Science
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DEC 19 1938

THIS NUMBER COMPLETES VOLUME 46

Volume 46 December, 1938 Number 6

# SOIL SCIENCE

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Published Monthly by THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES, BALTIMORE, MARYLAND, U. S. A.

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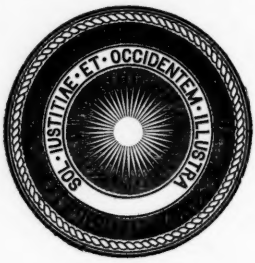
# SOIL SCIENCE

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Entered as second-class matter, May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879.
Subscription price $5.00 per volume. Single numbers, $1.00.

# OBSERVATIONS REGARDING SOILS OF NORTHERN AND CENTRAL MEXICO

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Received for publication June 3, 1938

In connection with selenium investigations conducted by this Bureau, a field trip[2] was recently made through northern and central Mexico. During the trip the soils[3] occurring in the region were studied as opportunity offered, and certain profile samples were collected for laboratory examination. The profiles described should not be taken as representing carefully defined soil series. Geographical names were assigned them only for the purpose of identification.

The itinerary (fig. 1) was from El Paso through Chihuahua, Torreon, Saltillo, and Monterrey; thence southward to Mexico City, and from Mexico City northwest through Queretaro to Irapuato. The return trip was via the Mexico City-Laredo Highway.

Observations were made of soils developed under widely varied conditions. These include differences in elevation from near sea-level to the summit of Navado de Toluca (approximately 15,000 feet); annual average rainfall ranging from 100 mm. (3.9 inches) to 3,000 mm. (118.1 inches); temperatures ranging from mild temperature to subtropical, and vegetation from scant shrub and grass to coniferous, deciduous, or dense, almost tropical, forests. The agricultural conditions were equally diverse. These include dry farming with a wide variety of crops, ranching, and farming where irrigation has been practiced for centuries as well as in more recently developed areas. Soils were observed which are erosive on gentle slopes; whereas other soils showed little or no evidence of erosion on long and exceedingly steep cultivated slopes.

Tropical soils, which exist in the southern part of Mexico, were not included in the itinerary.

## METHODS

The soil samples were treated according to the analytical practices of this laboratory. The mechanical analyses were made by the pipette method

[1] The writers wish to express their appreciation for the helpful suggestions and criticisms given by Horace G. Byers during the preparation of this paper.

[2] The Mexican government was represented by José Figueroa, whose knowledge of local conditions and whose energetic assistance were extremely valuable.

[3] The soils have been grouped in accordance with the principles outlined by Marbut (13), Kellogg (11), and Shaw (20).

described by Olmstead, Alexander, and Middleton (15). The approximate amount of organic matter determined by the hydrogen peroxide method is included with the mechanical analyses. All the chemical analyses except those for selenium and organic matter were made according to the procedure described by Robinson (16). The organic matter was determined by the combustion method as detailed by Alexander and Byers (1). Selenium was determined by the method outlined by Robinson, et al. (17) and by Williams (22).

The colloids were extracted three to eight times from 100 to 1,000 gm. of soil with the aid of a supercentrifuge operating at 1,650 revolutions per minute, as described by Brown and Byers (3). It is presumed that very few of the colloid particles exceed 0.3 $\mu$ in diameter and most of them are much less.

The pH values of the air-dried soils were determined by the hydrogen electrode as described by Bailey (2), and were checked by the glass electrode. The approximate salt content was determined by the electrolytic bridge as described by Davis (9).

Certain derived data were calculated from the analytical results and are included in the tables. The discussions of these data and of the analytical results follow the field descriptions of the soils.

## RESULTS OF THE INVESTIGATION

### *Gray desert soils*

The first part of the trip southward from El Paso to Chihuahua was along a section of the old Camino Real—a road built from Mexico City to Santa Fe by Spanish viceroys before the days of Mexican independence. This is through a region of gray and red desert soils in which the dominant surface soil colors range from light gray to red. These soils are developed in a broad belt extending from El Paso southeastward to Torreon and Parras in Coahuila. Field observations indicate that the boundary of this group coincided roughly with the 200-mm. rainfall, as shown in figure 1. Isolated areas were observed, however, somewhat beyond this limit. Average monthly temperatures in this region range from about 41 to 77°F. (10). Rainfall is distributed throughout the year but is heavier during the summer months.

The desert soils are developed in a region characterized by a series of northwest-southeast mountain ranges and broad intervening structural valleys. Elevations within the valleys range from 3,500 to 4,500 feet (and those of the higher peaks from 7,000 to 8,000 feet). The mountains, which have precipitous slopes, consist of interbedded sandstones, shales, and limestones. In places these formations are capped or intruded by materials of igneous origin. Adjacent to the mountains are extensive areas of alluvial fans consisting largely of stone and coarse gravel. For greater distances the material is finer textured, largely silt, and is of lake-laid or of eolian origin. In many of the broader valleys the lowest elevations are temporary or permanent lakes. These are known locally as lagunas.

FIG. 1. RAINFALL MAP OF A PART OF MEXICO, SHOWING THE LOCATIONS OF THE PROFILES EXAMINED

The locations of analyzed samples are marked by solid black circles; those of other samples examined, by six-pointed stars. The isohyetal lines show the rainfall in millimeters; transpositions are made in the text.

Vegetation within the valleys is of the desert shrub type. It consists mainly of mesquite (*Prosopis* sp.), huisache (*Vachellia farnesiana*), catclaw (*Minosa* sp.), yucca (*Yucca* sp.), and cactus (*Opuntia* sp.). In places there is a sparse covering of short grasses, chiefly grama (*Bouteloua* sp.). Coarse grasses, mainly burro (*Scleropogon brevifolius*) and alkali scaton (*Sporobolus airoides*), are found in the laguna basins. The mountain slopes are sparsely covered with small oak (*Quercus* sp.) and other shrubs.

Regional characteristics are well expressed in the soils developed from old alluvial lake-laid or eolian-deposited materials found in the broad valleys. These materials are finer textured and, generally speaking, have remained in place for a longer period than the coarse gravelly materials of the alluvial fans. Because of their finer texture they are more responsive to soil-forming processes. Characteristics common to these soils are: scattering of highly polished pebbles, commonly referred to as the desert pavement; slightly cemented layer varying in thickness from one-eighth to one-half inch and broken into polygons, sometimes called desert crust; light gray layer of finely granular structure extending to depths of 1½ to 6 inches; a slightly heavier horizon with cloddy structure. Although soils in which the regional characteristics are well developed may be observed at various points from El Paso southward, 41 miles north of Torreon a profile was noted which best revealed these characteristics. A description of the profile follows:

*Torreon sandy clay loam*

1. 0–1½ inches, light gray sandy clay, with the upper one-half inch slightly cemented. The remainder of this layer has finely granular structure. This layer does not effervesce with dilute hydrochloric acid.
2. 1½–12 inches, gray to light grayish brown somewhat heavier sandy clay, with medium to coarse cloddy structure; noncalcareous.
3. 12–20 inches, light grayish brown clay loam with slightly prismatic structure. This layer is calcareous. It contains numerous grass roots.
4. 20–32 inches, light gray silty clay loam with soft crumb structure. It is likewise calcareous, but is distinctly gray and contains fewer grass roots than the layer above.
5. 32–60 inches, light gray silt loam with small limestone fragments. It has pulverulent structure, is calcareous, and contains some charcoal fragments. The origin of the charcoal in this layer is problematical. It is probably the remains of a brush root which has burned deeply into the ground.

The profile is situated on nearly level topography. It is developed under sparse shrub vegetation and an average annual rainfall of 8 inches.[4]

Observations made at a number of locations on comparable topography indicate a close correlation between the depth and the texture of the surface layer. In clay or clay loam textures this layer varies from 1 to 1½ inches in depth; whereas in silt loams the variation is generally from 1½ to 6 inches. In

[4] A 40-year average as recorded by a private station at Tlahualilo at approximately the same elevation 8 miles north of the profile.

every instance, where the material was not cemented, finely granular structure was evident in this layer.

Soils developed from the old alluvial fans vary both in surface texture and in degree of profile development in contrast to the rather uniform development on the finer valley materials. In general, the texture varies from coarse sandy loam to gritty clay loam. Depths to the underlying gravel in the sandy soils vary from 6 inches to 3 feet; whereas in the clay loams the range is 3 or more feet. In the coarse sandy loams there is scant differentiation into horizons. In the clay loams the differentiation is similar to that of the valley soils, but the dominating colors are reddish brown to red in contrast to the gray soils developed from the more silty materials.

The Torreon sandy clay loam is nearly a typical gray desert soil. It is characteristic of an enormous area. Associated with it are azonal soils. The laboratory data of this profile are given in tables 1 to 4.

The mechanical analyses are shown in table 1. Although slight morphological differences in the soil were observed between the 12–20-inch and the 20–32-inch depths, these together constitute the zone of carbonate accumulation. The greatest accumulation of colloid occurs in the third layer, which is probably the mean high level water penetration. The increase in silt content with depth suggests that the parent material was lake land or of eolian origin.

The chemical analyses (table 2) of the soil give additional supplementary information about the development of this profile. The low calcium content and the absence of carbonates indicate complete removal of calcium carbonate from the first 12 inches of the soil and an accumulation in layers 3 and 4, the mean maximum depth of rain water penetration corresponding to the lower depth. The high potassium and sodium indicate incomplete decomposition of feldspars. The feldspars and the low degree of leaching of the soil are together responsible for the pH values found in layers 1 and 2.

The organic matter of horizon 5, as calculated from carbon present, is 2.12 per cent. Microscopic inspection of the soil disclosed many black particles, more or less decomposed. It is apparent that charcoal particles are present in considerable amount. Hence the use of the Wolff factor in this case is misleading.

The chemical analyses of the colloids are shown in table 3. The high organic matter in the colloid of horizon 5 also confirms the presence of carbon as shown in the soil. The presence of much more sodium in the colloid of horizon 1 than in horizons 2 and 3, in spite of thorough washing during colloid extraction, explains in part the high pH of this horizon. The high silica content throughout the profile indicates relatively little hydrolysis of the clay minerals whether translocated or not.

The derived data in table 4 more specifically indicate the slight variability in composition of the clay minerals. The colloids of the third layer show slightly lower ratios of silica to iron oxide, to the bases, and to water of con-

## TABLE 1

*Mechanical analyses* of Mexican soils*

| SAMPLE NUMBER | HORIZON | DEPTH | FINE GRAVEL, 2–1 MM. | COURSE SAND, 1–0.5 MM. | MEDIUM SAND, 0.5–0.25 MM. | FINE SAND, 0.25–0.1 MM. | VERY FINE SAND 0.1–0.05 MM. | SILT, 0.05–0.005 MM. | CLAY, 0.005–0 MM. | COLLOID, 0.002–0 MM. | ORGANIC MATTER BY $H_2O_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *inches* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| *Torreon sandy clay loam, Torreon, Coahuila* | | | | | | | | | | | |
| B-20799 | 1 | 0–1½ | 0.0 | 0.4 | 2.2 | 27.7 | 22.6 | 19.0 | 27.5 | 19.3 | 0.3 |
| B-20800 | 2 | 1½–12 | 0.0 | 0.2 | 1.5 | 22.1 | 21.0 | 21.0 | 33.9 | 25.8 | 0.1 |
| B-20801 | 3 | 12–20 | 0.2 | 0.4 | 2.1 | 20.0 | 18.2 | 20.4 | 38.1 | 28.2 | 0.2 |
| B-20802 | 4 | 20–32 | 1.4 | 1.8 | 1.3 | 13.7 | 20.8 | 27.5 | 33.2 | 22.1 | 0.2 |
| B-20803 | 5 | 32–60 | 0.3 | 0.4 | 0.4 | 9.5 | 15.6 | 44.5 | 28.9 | 22.6 | 0.1 |
| *Juarez clay, Juarez, Chihuahua* | | | | | | | | | | | |
| B-20717 | 1 | 0–6 | 1.4 | 1.9 | 1.3 | 4.15 | 14.5 | 13.2 | 52.7 | 42.9 | 0.2 |
| B-20718 | 2 | 6–12 | 0.7 | 0.9 | 0.7 | 7.9 | 12.2 | 14.9 | 61.2 | 49.4 | 0.2 |
| B-20719 | 3 | 12–27 | 0.4 | 0.6 | 0.7 | 8.2 | 11.2 | 18.0 | 58.9 | 48.7 | 0.0 |
| B-20720 | 4 | 27–36 | 0.9 | 1.2 | 0.9 | 7.1 | 9.5 | 15.7 | 62.7 | 52.2 | 0.4 |
| B-20721 | 5 | 36–48 | 0.6 | 1.6 | 1.0 | 8.2 | 10.1 | 13.0 | 63.6 | 55.0 | 0.4 |
| *Agua Neuva sandy loam, Agua Neuva, Chihuahua* | | | | | | | | | | | |
| B-20733 | 1 | 0–4 | 10.3 | 15.5 | 12.3 | 30.4 | 12.3 | 5.0 | 12.6 | 10.0 | 1.1 |
| B-20734 | 2 | 4–10 | 12.6 | 18.2 | 12.0 | 27.1 | 10.5 | 6.1 | 12.3 | 11.1 | 0.9 |
| B-20735 | 3 | 10–18 | 7.6 | 14.3 | 11.3 | 28.6 | 13.0 | 6.9 | 16.4 | 14.2 | 1.5 |
| B-20736 | 4 | 18–30 | 3.1 | 7.5 | 9.8 | 38.7 | 16.6 | 5.4 | 18.2 | 16.5 | 0.1 |
| B-20737 | 5 | 30–42 | 0.2 | 5.8 | 8.2 | 26.5 | 10.5 | 7.6 | 38.7 | 31.7 | 0.1 |
| B-20738 | 6 | 42+ | 1.3 | 4.1 | 7.3 | 27.2 | 12.3 | 12.4 | 34.6 | 24.2 | 0.0 |
| *Irapuato clay loam, Irapuato, Guanajuato* | | | | | | | | | | | |
| B-20896 | 1 | 0–10 | 0.5 | 1.0 | 0.9 | 8.2 | 13.0 | 41.6 | 30.8 | 24.8 | 3.3 |
| B-20897 | 2 | 10–23 | 0.2 | 0.5 | 0.6 | 7.2 | 18.0 | 47.5 | 25.5 | 21.1 | 0.3 |
| B-20898 | 3 | 23–28 | 0.1 | 0.1 | 0.2 | 8.6 | 40.0 | 34.2 | 16.4 | 13.2 | 0.0 |
| B-20899 | 4 | 28–35 | 0.0 | 0.1 | 0.6 | 3.5 | 9.1 | 41.0 | 45.2 | 37.4 | 0.1 |
| B-20900 | 5 | 35–55 | 0.1 | 0.1 | 0.1 | 0.7 | 2.7 | 26.4 | 69.4 | 63.7 | 0.3 |
| B-20901 | 6 | 55–97 | 0.8 | 0.9 | 0.6 | 1.6 | 2.8 | 22.1 | 70.6 | 59.6 | 0.3 |
| B-20902 | 7 | 97–144 | 0.7 | 0.9 | 0.7 | 3.0 | 8.6 | 34.1 | 51.1 | 40.9 | 0.7 |
| B-20903 | 8 | 144+ | 0.3 | 1.1 | 1.0 | 2.8 | 7.6 | 24.9 | 61.3 | 48.2 | 0.8 |
| *Queretaro clay, Queretaro, Queretaro* | | | | | | | | | | | |
| B-20947 | 1 | 0–3 | 1.1 | 1.2 | 0.8 | 2.5 | 2.7 | 21.7 | 67.9 | 57.5 | 1.7 |
| B-20948 | 2 | 3–8 | 0.8 | 0.7 | 0.8 | 2.4 | 3.3 | 20.3 | 69.8 | 60.5 | 1.7 |
| B-20949 | 3 | 8–30 | 0.1 | 0.3 | 0.5 | 1.7 | 2.0 | 15.5 | 78.6 | 69.4 | 1.2 |
| B-20950 | 4 | 30–48 | 0.1 | 0.2 | 0.2 | 1.1 | 1.8 | 12.7 | 82.5 | 73.0 | 1.2 |
| *Tamazunchale clay, Tamazunchale, San Luis Potosi* | | | | | | | | | | | |
| B-20973 | 1 | 0–3 | 0.3 | 0.7 | 0.7 | 2.2 | 2.4 | 21.3 | 66.3 | 58.4 | 5.2 |
| B-20974 | 2 | 3–20 | 0.0 | 0.2 | 0.3 | 0.8 | 0.9 | 8.7 | 87.0 | 84.1 | 1.9 |
| B-20975 | 3 | 20–48 | 0.0 | 0.1 | 0.1 | 0.4 | 0.4 | 3.6 | 94.5 | 92.3 | 0.7 |
| B-20976 | 4 | 48+ | 38.5 | 23.8 | 7.7 | 9.8 | 4.9 | 7.3 | 7.7 | 3.1 | 0.1 |

* Analyses by T. M. Shaw and E. F. Miles.

stitution than do the colloids of the layer immediately above or below. The ratios of iron oxide to alumina and of water to alumina are higher, and the ratios of water to iron oxide is lower, in the colloids of the third horizon than in the colloids of the eluviated layers or of the layer nearer the parent material. It seems apparent that although the conditions throughout the profile are nearly alike, the portion of the colloid in the upper layers suffering the greatest hydrolysis is that most readily translocated.

In many respects the colloid of this soil resembles that of Phillips sandy loam from Montana described by Brown, Rice, and Byers (5), although the latter is developed under somewhat higher rainfall and at a lower temperature than the former. The parent materials of the two soils are very similar in composition.

### *Intrazonal soils*

Of the intrazonal soils the solonchak soils are closely associated with the gray desert soils. They are found in many of the laguna basins which are subject to periodic flooding and subsequent evaporation, and likewise where the water table is near the surface and where, consequently, there is considerable capillary movement of water upwards. These soils vary in texture from silt loam to clay, and in color from light to dark gray or black. They have typically developed "buffalo wallow" microrelief; finely granular structure in the surface soil; and in places at lower depths, especially in the heavier textures, well-developed prismatic structure. An excellent example is found near Meoqui, Chihuahua. Here the surface soil is a heavy, black clay highly impregnated with light colored salts. The vegetation is chiefly coarse grass. In a nearby field further salinization has resulted through irrigation without adequate drainage. No profile sample of this soil was taken.

The solonchak soils are more widespread than the solonetz in northern Mexico. The reasons are obvious if the low rainfall of the area is considered. In most places, however, the rainfall is sufficient to have moistened the soil enough to produce hydrolysis of the primary rock minerals, but it has not been adequate to permit removal of these salts by percolating water. The flow of ground water is slow, if it occurs at all, and is at such depth as to have given no material aid in removing the soluble salts from the soil. In particularly favorable conditions near the laguna basins, however, enough surface water has penetrated the soil after each torrential rain to have caused a partial removal of soluble salts, and the usual solonchak profile in many places has some of the properties of a solonetz.

Most of the solonchak soils noted have light gray, highly dispersed surface horizons underlain at depths of 4 to 6 inches by heavier silt loam with slightly granular structure. This is underlain at depths of 20 to 30 inches by silt or loamy fine sand. The vegetation is usually coarse grasses such as burro grass and alkali scaton. An extensive area of solonchak soil lies 60 to 70 miles south of Juarez; and another, in the laguna basin northwest of El Sauz, Chihuahua.

TABLE 2

*Chemical analyses* of Mexican soils*

| SAMPLE NUMBER | HORIZON | DEPTH | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | MgO | CaO | $K_2O$ | $Na_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $SO_3$ | IGNITION LOSS | TOTAL | ORGANIC MATTER† | $CO_2$‡ | N | SOLUBLE SALTS | pH | Se |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *inches* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *p.p.m.* | | *p.p.m.* |
| *Torreon sandy clay loam, Torreon, Coahuila* | | | | | | | | | | | | | | | | | | | | | |
| B-20799 | 1 | 0–1½ | 70.38 | 2.90 | 14.60 | 1.08 | 1.50 | 3.82 | 1.79 | 0.42 | 0.07 | 0.10 | 0.08 | 3.39 | 100.13 | 0.71 | 0.00 | 0.05 | 360 | 8.1 | .... |
| B-20800 | 2 | 1½–12 | 69.89 | 3.18 | 15.10 | 1.27 | 1.50 | 3.76 | 1.82 | 0.42 | 0.11 | 0.08 | 0.05 | 3.38 | 100.53 | 0.52 | 0.00 | 0.04 | 780 | 7.9 | .... |
| B-20801 | 3 | 12–20 | 66.36 | 2.89 | 14.43 | 1.17 | 4.27 | 3.54 | 1.58 | 0.39 | 0.10 | 0.09 | 0.10 | 5.54 | 100.46 | 0.35 | 2.42 | 0.04 | 1,630 | 7.9 | .... |
| B-20802 | 4 | 20–32 | 66.68 | 2.66 | 13.49 | 0.90 | 5.10 | 3.16 | 2.20 | 0.40 | 0.09 | 0.04 | 0.11 | 5.63 | 100.46 | 0.19 | 2.86 | 0.02 | 880 | 8.0 | .... |
| B-20803 | 5 | 32–60 | 67.38 | 2.76 | 13.75 | 0.95 | 3.62 | 3.28 | 1.80 | 0.40 | 0.08 | 0.05 | 0.01 | 5.95 | 100.03 | 2.12 | 1.89 | 0.02 | 660 | 8.2 | .... |
| *Juarez clay, Jaurez, Chihuahua* | | | | | | | | | | | | | | | | | | | | | |
| B-20717 | 1 | 0–6 | 57.77 | 3.96 | 13.58 | 2.22 | 8.33 | 2.76 | 2.10 | 0.52 | 0.11 | 0.18 | 0.09 | 8.82 | 100.44 | 0.90 | 5.24 | 0.05 | 3,250 | 8.8 | .... |
| B-20718 | 2 | 6–12 | 55.56 | 4.28 | 13.46 | 2.42 | 8.80 | 2.62 | 2.28 | 0.51 | 0.12 | 0.21 | 0.18 | 9.74 | 100.18 | 0.89 | 5.74 | 0.04 | 7,960 | 8.6 | .... |
| B-20719 | 3 | 12–27 | 52.45 | 4.24 | 13.18 | 2.85 | 10.60 | 2.57 | 2.14 | 0.52 | 0.11 | 0.23 | 0.73 | 10.90 | 100.25 | 0.77 | 6.92 | 0.03 | 12,600 | 8.1 | .... |
| B-20720 | 4 | 27–36 | 44.12 | 3.90 | 11.57 | 3.02 | 16.36 | 2.10 | 1.87 | 0.44 | 0.09 | 0.25 | 0.51 | 15.65 | 99.88 | 0.79 | 11.59 | 0.03 | 14,500 | 8.3 | .... |
| B-20721 | 5 | 36–48 | 48.11 | 4.45 | 12.76 | 3.24 | 12.62 | 2.28 | 2.32 | 0.58 | 0.09 | 0.22 | 0.41 | 13.00 | 100.03 | 0.62 | 9.09 | 0.04 | 13,320 | 8.5 | .... |
| *Agua Neuva sandy loam, Agua Neuva, Chihuahua* | | | | | | | | | | | | | | | | | | | | | |
| B-20733 | 1 | 0–4 | 77.00 | 2.93 | 9.75 | 0.61 | 1.17 | 3.55 | 1.78 | 0.33 | 0.06 | 0.12 | 0.04 | 2.28 | 99.62 | 1.42 | 0.37 | 0.07 | 420 | 8.1 | .... |
| B-20734 | 2 | 4–10 | 76.20 | 2.78 | 9.77 | 0.57 | 1.47 | 3.77 | 1.82 | 0.28 | 0.04 | 0.07 | 0.02 | 3.04 | 99.83 | 1.08 | 0.61 | 0.06 | 450 | 7.9 | .... |
| B-20735 | 3 | 10–18 | 75.00 | 2.74 | 9.98 | 0.60 | 2.27 | 3.72 | 1.79 | 0.23 | 0.05 | 0.05 | 0.01 | 3.29 | 99.73 | 0.77 | 1.15 | 0.04 | 470 | 8.1 | .... |
| B-20736 | 4 | 18–30 | 73.30 | 2.89 | 9.88 | 0.72 | 3.36 | 3.58 | 2.06 | 0.23 | 0.04 | 0.06 | 0.03 | 3.84 | 100.08 | 0.39 | 1.93 | 0.03 | 640 | 8.2 | .... |
| B-20737 | 5 | 30–42 | 57.40 | 3.23 | 8.91 | 1.67 | 12.90 | 2.65 | 1.71 | 0.24 | 0.09 | 0.04 | 0.03 | 11.00 | 99.87 | 0.34 | 8.62 | 0.02 | 3,240 | 9.3 | .... |
| B-20738 | 6 | 42+ | 55.30 | 2.85 | 8.80 | 1.18 | 14.64 | 2.50 | 1.82 | 0.25 | 0.07 | 0.03 | 0.03 | 12.52 | 99.99 | 0.13 | 10.59 | 0.01 | 4,770 | 9.7 | .... |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Irapuato clay loam, Irapuato, Guanajuato* | | | | | | | | | | | | | | | | | | | | |
| B-20896 | 1 | 0–10 | 63.21 | 4.72 | 14.61 | 1.91 | 2.29 | 2.04 | 2.07 | 0.69 | 0.13 | 0.15 | 0.12 | 8.59 | 100.53 | 5.05 | 0.00 | 0.28 | 960 | 7.6 | 1.5 |
| B-20897 | 2 | 10–23 | 65.60 | 5.07 | 14.87 | 2.08 | 2.65 | 1.91 | 1.92 | 0.81 | 0.13 | 0.10 | 0.07 | 5.02 | 100.23 | 1.47 | 0.57 | 0.09 | 1,230 | 8.1 | 0.03 |
| B-20898 | 3 | 23–28 | 66.69 | 5.05 | 15.21 | 2.11 | 2.34 | 1.95 | 2.46 | 0.73 | 0.12 | 0.06 | 0.11 | 3.48 | 100.31 | 0.69 | 0.18 | 0.03 | 2,730 | 8.0 | 0.05 |
| B-30899 | 4 | 28–35 | 66.08 | 5.00 | 15.98 | 1.80 | 1.82 | 1.50 | 2.08 | 0.74 | 0.11 | 0.06 | 0.08 | 5.29 | 100.54 | 1.09 | 0.00 | 0.04 | 2,730 | 7.8 | 0.05 |
| B-20900 | 5 | 35–55 | 60.99 | 6.14 | 18.09 | 2.22 | 1.75 | 1.79 | 1.28 | 0.71 | 0.14 | 0.09 | 0.07 | 7.21 | 100.48 | 1.50 | 0.20 | 0.06 | 1,470 | 8.0 | 0.03 |
| B-20901 | 6 | 55–97 | 63.43 | 5.07 | 16.97 | 1.86 | 1.82 | 1.70 | 1.11 | 0.66 | 0.12 | 0.07 | 0.08 | 7.19 | 100.08 | 1.22 | 0.76 | 0.04 | 840 | 8.0 | 0.02 |
| B-20902 | 7 | 97–144 | 68.03 | 3.63 | 15.65 | 1.07 | 1.47 | 2.06 | 1.45 | 0.47 | 0.09 | 0.06 | 0.06 | 5.90 | 99.94 | 0.13 | 0.67 | 0.03 | 960 | 8.3 | 0.01 |
| B-20903 | 8 | 144–216 | 63.31 | 5.55 | 17.25 | 2.12 | 1.62 | 2.18 | 1.48 | 0.70 | 0.12 | 0.12 | 0.05 | 5.68 | 100.18 | 0.25 | 0.00 | 0.02 | 890 | 8.2 | 0.01 |
| *Queretaro clay, Queretaro, Queretaro* | | | | | | | | | | | | | | | | | | | | |
| B-20947 | 1 | 0–3 | 60.79 | 4.55 | 16.94 | 1.52 | 2.92 | 1.30 | 1.06 | 0.84 | 0.11 | 0.09 | 0.09 | 10.34 | 100.55 | 4.40 | 0.00 | 0.20 | 690 | 7.8 | .... |
| B-20948 | 2 | 3–8 | 61.38 | 4.62 | 17.52 | 1.47 | 2.75 | 1.25 | 1.04 | 0.85 | 0.12 | 0.09 | 0.08 | 9.30 | 100.47 | 3.42 | 0.00 | 0.14 | 510 | 7.9 | .... |
| B-20949 | 3 | 8–30 | 61.97 | 4.88 | 17.66 | 1.46 | 2.33 | 1.18 | 0.77 | 0.85 | 0.11 | 0.08 | 0.06 | 8.78 | 100.13 | 2.19 | 0.00 | 0.09 | 250 | 7.7 | .... |
| B-20950 | 4 | 30–48 | 62.73 | 4.95 | 18.16 | 1.63 | 2.00 | 1.09 | 0.82 | 0.81 | 0.11 | 0.05 | 0.05 | 7.98 | 100.11 | 1.47 | 0.00 | 0.06 | 200 | 7.5 | .... |
| *Tamazunchale clay, Tamazunchale, San Luis Potosi* | | | | | | | | | | | | | | | | | | | | |
| B-20973 | 1 | 0–3 | 47.90 | 8.47 | 24.06 | 0.49 | 1.15 | 0.08 | 0.05 | 1.56 | 0.16 | 0.09 | 0.11 | 16.31 | 100.44 | 8.00 | 0.00 | 0.26 | 670 | 6.9 | .... |
| B-20974 | 2 | 3–20 | 44.24 | 9.26 | 31.44 | 0.37 | 0.55 | 0.04 | 0.06 | 1.36 | 0.08 | 0.06 | 0.06 | 12.93 | 100.45 | 1.74 | 0.00 | 0.08 | <149 | 6.0 | .... |
| B-20975 | 3 | 20–48 | 40.35 | 9.32 | 34.52 | 0.40 | 0.62 | 0.04 | 0.09 | 1.04 | 0.06 | 0.03 | 0.06 | 13.65 | 100.18 | 1.35 | 0.00 | 0.05 | <149 | 6.1 | .... |
| B-20976 | Lime-stone | 48+ | 0.84 | 0.09 | 0.37 | 0.50 | 55.31 | Tr. | 0.08 | Tr. | 0.03 | 0.03 | 0.10 | 42.90 | 100.25 | .... | 43.05 | .... | 260 | 8.5 | .... |

* Determined by Glen Edgington, except analyses of Agua Neuva profile and the following analyses: organic matter, $CO_2$, and N by W. M. Noble; soluble salts by I. C. Brown; pH by E. H. Bailey; and Se by K. T. Williams.

† Determined by the combustion method ($CO_2 \times 0.471$).

‡ $CO_2$ of the carbonates.

TABLE 3

*Chemical analyses* of Mexican soil colloids*

| SAMPLE NUMBER | HORIZON | DEPTH | COLLOID EXTRACTED | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | MgO | CaO | $K_2O$ | $Na_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $SO_3$ | IGNITION LOSS | TOTAL | ORGANIC MATTER† | $CO_2$‡ | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *inches* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| *Torreon sandy clay loam Torreon, Coahuila* | | | | | | | | | | | | | | | | | | | |
| B-20799 | 1 | 0–1½ | 40 | 55.80 | 6.94 | 18.91 | 2.86 | 1.74 | 3.61 | 0.46 | 0.56 | 0.11 | 0.39 | 0.06 | 8.03 | 99.47 | 1.50 | 0.00 | 0.14 |
| B-20800 | 2 | 1½–12 | 61 | 56.60 | 6.28 | 20.32 | 2.80 | 1.49 | 3.13 | 0.07 | 0.48 | 0.13 | 0.22 | 0.02 | 7.88 | 99.62 | 0.85 | 0.05 | 0.09 |
| B-20801 | 3 | 12–20 | 45 | 54.40 | 7.17 | 17.13 | 3.06 | 4.66 | 3.06 | 0.07 | 0.54 | 0.19 | 0.31 | 0.01 | 9.64 | 100.24 | 0.57 | 2.27 | 0.09 |
| B-20802 | 4 | 20–32 | 48 | 56.15 | 7.22 | 18.67 | 2.71 | 3.35 | 2.24 | 0.35 | 0.49 | 0.08 | 0.13 | 0.07 | 8.69 | 100.15 | 0.58 | 1.05 | 0.09 |
| B-20803 | 5 | 32–60 | 41 | 51.38 | 6.06 | 18.48 | 2.56 | 3.04 | 1.85 | 0.29 | 0.46 | 0.10 | 0.09 | 0.06 | 15.42 | 99.79 | 8.46 | 0.71 | 0.04 |
| *Juarez clay, Juarez, Chihuahua* | | | | | | | | | | | | | | | | | | | |
| B-20717 | 1 | 0–6 | 84 | 48.89 | 7.75 | 16.26 | 4.30 | 6.72 | 2.39 | 0.32 | 0.67 | 0.12 | 0.23 | 0.03 | 12.44 | 100.12 | 1.24 | 3.84 | 0.09 |
| B-20718 | 2 | 6–12 | 73 | 48.70 | 8.10 | 15.89 | 4.39 | 7.00 | 2.28 | 0.35 | 0.65 | 0.09 | 0.29 | 0.05 | 12.22 | 100.01 | 0.82 | 3.58 | 0.09 |
| B-20719 | 3 | 12–27 | 87 | 48.65 | 7.65 | 15.87 | 4.34 | 7.33 | 2.27 | 0.35 | 0.55 | 0.08 | 0.33 | 0.07 | 12.07 | 99.56 | 0.83 | 0.40 | 0.08 |
| B-20720 | 4 | 27–36 | 79 | 43.60 | 6.80 | 13.47 | 4.99 | 12.07 | 2.06 | 0.47 | 0.58 | 0.07 | 0.33 | 0.10 | 15.05 | 99.59 | 0.97 | 8.33 | 0.08 |
| B-20721 | 5 | 36–48 | 68 | 47.50 | 7.74 | 14.94 | 5.31 | 8.25 | 2.12 | 0.36 | 0.62 | 0.06 | 0.33 | 0.11 | 12.81 | 100.15 | 0.69 | 5.04 | 0.06 |
| *Agua Neuva sandy loam, Agua Neuva, Chihuahua* | | | | | | | | | | | | | | | | | | | |
| B-20733 | 1 | 0–4 | 32 | 53.95 | 6.79 | 15.95 | 3.09 | 3.26 | 3.18 | 0.56 | 0.51 | 0.15 | 0.28 | 0.18 | 12.50 | 100.44 | 5.32 | 0.05 | 0.39 |
| B-20734 | 2 | 4–10 | 40 | 54.95 | 6.86 | 15.38 | 3.27 | 4.44 | 3.08 | 0.52 | 0.46 | 0.14 | 0.26 | 0.08 | 12.37 | 99.94 | 4.43 | 0.74 | 0.32 |
| B-20735 | 3 | 10–18 | 45 | 52.60 | 7.08 | 15.49 | 3.44 | 5.03 | 2.98 | 0.43 | 0.43 | 0.12 | 0.20 | 0.07 | 11.94 | 99.81 | 3.04 | 1.52 | 0.22 |
| B-20736 | 4 | 18–30 | 67 | 54.80 | 7.37 | 15.45 | 3.99 | 4.53 | 2.73 | 0.53 | 0.44 | 0.09 | 0.12 | 0.00 | 10.45 | 100.50 | 1.46 | 1.13 | 0.12 |
| B-20737 | 5 | 30–42 | 83 | 55.90 | 7.22 | 14.33 | 5.44 | 4.61 | 2.80 | 0.76 | 0.45 | 0.15 | 0.05 | 0.02 | 8.81 | 100.54 | 0.70 | 0.42 | 0.07 |
| B-20738 | 6 | 42+ | 35 | 55.35 | 7.54 | 14.87 | 4.79 | 4.67 | 2.38 | 0.81 | 0.51 | 0.10 | 0.10 | 0.02 | 8.71 | 99.84 | 0.33 | 0.56 | 0.06 |

*Irapuato clay loam, Irapuato, Guanajuato*

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-20896 | 1 | 0–10 | 62 | 49.20 | 9.97 | 20.92 | 1.92 | 1.53 | 1.56 | 0.21 | 0.60 | 0.13 | 0.26 | 0.10 | 13.86 | 100.26 | 4.64 | 0.00 | 0.35 |
| B-20897 | 2 | 10–23 | 59 | 49.40 | 10.85 | 21.70 | 2.25 | 1.33 | 1.55 | 0.18 | 0.51 | 0.15 | 0.16 | 0.03 | 12.15 | 100.26 | 2.72 | 0.00 | 0.19 |
| B-20898 | 3 | 23–28 | 60 | 48.85 | 11.09 | 21.78 | 2.84 | 1.32 | 1.40 | 0.26 | 0.58 | 0.16 | 0.15 | 0.02 | 11.54 | 99.99 | 2.14 | 0.00 | 0.15 |
| B-20899 | 4 | 28–35 | 70 | 51.30 | 9.80 | 21.76 | 2.39 | 1.19 | 1.26 | 0.27 | 0.62 | 0.08 | 0.11 | 0.01 | 11.02 | 99.81 | 1.42 | 0.00 | 0.11 |
| B-20900 | 5 | 35–55 | 68 | 50.80 | 9.73 | 22.39 | 2.52 | 1.20 | 1.16 | 0.20 | 0.56 | 0.10 | 0.10 | 0.01 | 11.26 | 100.03 | 1.45 | 0.00 | 0.10 |
| B-20901 | 6 | 55–97 | 80 | 52.30 | 8.21 | 23.02 | 2.33 | 1.20 | 1.34 | 0.26 | 0.56 | 0.05 | 0.06 | 0.02 | 10.59 | 99.94 | 1.42 | 0.00 | 0.08 |
| B-20902 | 7 | 97–144 | 54 | 55.26 | 7.31 | 22.59 | 1.90 | 1.16 | 0.99 | 0.00 | 0.61 | 0.06 | 0.09 | 0.02 | 10.15 | 100.14 | 0.87 | 0.00 | 0.11 |
| B-20903 | 8 | 144–216 | 61 | 52.80 | 8.83 | 21.89 | 2.79 | 1.63 | 1.13 | 0.00 | 0.59 | 0.10 | 0.22 | 0.02 | 10.11 | 100.09 | 0.55 | 0.00 | 0.07 |
| | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | *Queretaro clay, Queretaro, Queretaro* | | | | | | | | | |
| B-20947 | 1 | 0–3 | 57 | 53.10 | 7.00 | 21.81 | 2.09 | 2.11 | 1.04 | 0.09 | 0.64 | 0.07 | 0.15 | 0.05 | 11.46 | 99.61 | 2.37 | 0.06 | 0.18 |
| B-20948 | 2 | 3–8 | 64 | 53.40 | 7.20 | 22.39 | 2.06 | 1.87 | 0.93 | 0.06 | 0.67 | 0.06 | 0.14 | 0.03 | 11.38 | 100.19 | 2.22 | 0.06 | 0.13 |
| B-20949 | 3 | 8–30 | 63 | 54.15 | 7.20 | 22.03 | 1.95 | 1.97 | 0.88 | 0.07 | 0.78 | 0.11 | 0.09 | 0.01 | 10.78 | 100.02 | 1.64 | 0.00 | 0.08 |
| B-20950 | 4 | 30–48 | 74 | 54.19 | 7.46 | 22.29 | 1.92 | 1.74 | 0.56 | 0.00 | 0.90 | 0.06 | 0.15 | 0.02 | 10.50 | 99.79 | 1.23 | 0.00 | 0.08 |
| | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | *Tamazunchale clay, Tamazunchale, San Luis Potosi* | | | | | | | | | |
| B-20973 | 1 | 0–3 | 54 | 37.35 | 10.65 | 32.86 | 0.50 | 1.01 | 0.12 | 0.00 | 1.15 | 0.05 | 0.29 | 0.04 | 16.25 | 100.27 | 3.68 | 0.05 | 0.21 |
| B-20974 | 2 | 3–20 | 82 | 38.95 | 10.40 | 34.64 | 0.28 | 0.53 | 0.12 | 0.00 | 0.97 | 0.19 | 0.09 | 0.02 | 14.01 | 100.20 | 1.62 | 0.05 | 0.08 |
| B-20975 | 3 | 20–48 | 85 | 39.50 | 10.03 | 34.65 | 0.28 | 0.57 | 0.11 | 0.00 | 0.93 | 0.10 | 0.09 | 0.02 | 13.93 | 100.21 | 1.32 | 0.00 | 0.08 |

* Organic matter, $CO_2$, and N determined by W. M. Noble; sample B-20803 determined by Glen Edington.

† Determined by the combustion method ($CO_2 \times 0.471$).

‡ $CO_2$ of the carbonates.

TABLE 4

*Derived data: Mexican soil colloids*

| SAMPLE NUMBER | HORIZON | DEPTH | $\frac{SiO_2}{Fe_2O_3 \cdot Al_2O_3}$ | $\frac{SiO_2}{Fe_2O_3}$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{Fe_2O_3}{Al_2O_3}$ | $\frac{SiO_2}{\text{TOTAL BASES}^*}$ | $\frac{SiO_2}{H_2O\dagger}$ | $\frac{H_2O}{Fe_2O_3 \cdot Al_2O_3}$ | $\frac{H_2O}{Fe_2O_3}$ | $\frac{H_2O}{Al_2O_3}$ | COMBINED WATER‡ | COMBINED WATER OF THE SOIL ACID§ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *inches* | | | | | | | | | | *per cent* | *per cent* |
| *Torreon sandy clay loam, Torreon, Coahuila* | | | | | | | | | | | | | |
| B-20799 | 1 | 0–1½ | 3.89 | 21.41 | 5.01 | 0.234 | 6.30 | 1.82 | 2.14 | 11.77 | 2.75 | 6.53 | 9.33 |
| B-20800 | 2 | 1½–12 | 3.95 | 23.98 | 4.72 | 0.197 | 7.29 | 1.82 | 2.17 | 13.16 | 2.59 | 6.98 | 9.40 |
| B-20801 | 3 | 12–20 | 4.26 | 20.18 | 5.40 | 0.268 | 6.43 | 1.74 | 2.45 | 11.60 | 3.10 | 6.80 | 9.62 |
| B-20802 | 4 | 20–32 | 4.12 | 20.79 | 5.13 | 0.247 | 7.10 | 1.79 | 2.30 | 11.61 | 2.87 | 7.06 | 9.61 |
| B-20803 | 5 | 32–60 | 3.45 | 19.90 | 4.17 | 0.209 | 6.04 | 1.60 | 2.16 | 12.44 | 2.61 | 6.25 | 9.36 |
| *Juarez clay, Juarez, Chihuahua* | | | | | | | | | | | | | |
| B-20717 | 1 | 0–6 | 3.90 | 16.78 | 5.04 | 0.300 | 4.79 | 1.41 | 2.77 | 11.90 | 3.57 | 7.36 | 10.97 |
| B-20718 | 2 | 6–12 | 3.93 | 16.02 | 5.21 | 0.325 | 4.45 | 1.33 | 2.96 | 12.05 | 3.92 | 7.62 | 11.46 |
| B-20719 | 3 | 12–27 | 3.93 | 17.09 | 5.11 | 0.299 | 4.82 | 1.48 | 2.66 | 11.55 | 3.46 | 6.84 | 10.42 |
| B-20720 | 4 | 27–36 | 4.16 | 17.09 | 5.50 | 0.322 | 4.06 | 1.46 | 2.85 | 11.70 | 3.77 | 5.75 | 9.90 |
| B-20721 | 5 | 36–48 | 4.06 | 16.41 | 5.40 | 0.329 | 4.11 | 1.35 | 3.01 | 12.16 | 4.00 | 7.08 | 11.20 |
| *Agua Neuva sandy loam, Agua Neuva, Chihuahua* | | | | | | | | | | | | | |
| B-20733 | 1 | 0–4 | 4.51 | 21.15 | 5.78 | 0.273 | 4.97 | 1.56 | 2.89 | 13.55 | 3.70 | 7.13 | 10.94 |
| B-20734 | 2 | 4–10 | 4.71 | 21.29 | 6.02 | 0.283 | 5.24 | 1.60 | 2.94 | 13.30 | 3.76 | 7.20 | 10.86 |
| B-20735 | 3 | 10–18 | 4.47 | 19.73 | 5.76 | 0.292 | 4.91 | 1.49 | 3.00 | 13.24 | 3.87 | 7.38 | 11.10 |
| B-20736 | 4 | 18–30 | 4.61 | 19.75 | 6.02 | 0.305 | 4.77 | 1.45 | 3.18 | 13.62 | 4.15 | 7.86 | 11.83 |
| B-20737 | 5 | 30–42 | 5.02 | 20.60 | 6.62 | 0.321 | 3.46 | 1.34 | 3.75 | 15.36 | 4.94 | 7.69 | 12.66 |
| B-20738 | 6 | 42+ | 4.77 | 19.55 | 6.32 | 0.318 | 4.05 | 1.40 | 3.41 | 13.96 | 4.52 | 7.82 | 12.02 |
| *Irapuato clay loam, Irapuato, Gunajuato* | | | | | | | | | | | | | |
| B-20896 | 1 | 0–10 | 3.06 | 13.14 | 4.00 | 0.304 | 8.50 | 1.35 | 2.27 | 9.74 | 2.96 | 9.22 | 11.49 |
| B-20897 | 2 | 10–23 | 2.93 | 12.10 | 3.87 | 0.299 | 8.41 | 1.32 | 2.22 | 9.16 | 2.93 | 9.43 | 11.50 |
| B-20898 | 3 | 23–28 | 2.89 | 11.75 | 3.83 | 0.297 | 7.22 | 1.31 | 2.21 | 8.95 | 2.92 | 9.40 | 11.68 |
| B-20899 | 4 | 28–35 | 3.10 | 13.70 | 4.01 | 0.341 | 8.58 | 1.35 | 2.29 | 10.15 | 2.97 | 9.60 | 11.53 |
| B-20900 | 5 | 35–55 | 3.02 | 13.87 | 3.86 | 0.278 | 8.52 | 1.31 | 2.31 | 10.59 | 2.95 | 9.81 | 11.76 |
| B-20901 | 6 | 55–97 | 3.14 | 16.95 | 3.85 | 0.227 | 8.92 | 1.44 | 2.18 | 11.76 | 2.67 | 9.17 | 11.20 |
| B-20902 | 7 | 97–144 | 3.45 | 20.11 | 4.16 | 0.207 | 11.86 | 1.55 | 2.22 | 12.98 | 2.68 | 9.28 | 11.01 |
| B-20903 | 8 | 144–216 | 3.38 | 15.42 | 4.30 | 0.279 | 7.98 | 1.37 | 2.47 | 11.25 | 3.14 | 9.56 | 10.93 |
| *Queretaro clay, Queretaro, Queretaro* | | | | | | | | | | | | | |
| B-20947 | 1 | 0–3 | 3.43 | 20.20 | 4.13 | 0.204 | 8.80 | 1.46 | 2.35 | 13.84 | 2.83 | 9.03 | 11.14 |
| B-20948 | 2 | 3–8 | 3.36 | 19.75 | 4.15 | 0.210 | 9.46 | 1.48 | 2.27 | 13.85 | 2.80 | 9.10 | 11.05 |
| B-20949 | 3 | 8–30 | 3.45 | 20.05 | 4.18 | 0.209 | 9.70 | 1.46 | 2.36 | 13.74 | 2.86 | 9.14 | 11.01 |
| B-20950 | 4 | 30–48 | 3.40 | 19.31 | 4.13 | 0.214 | 10.67 | 1.51 | 2.25 | 12.79 | 2.73 | 9.27 | 10.93 |
| *Tamazunchale clay, Tamazunchale, San Luis Potosi* | | | | | | | | | | | | | |
| B-20973 | 1 | 0–3 | 1.60 | 9.33 | 1.93 | 0.207 | 20.40 | 0.751 | 2.13 | 12.29 | 2.57 | 12.62 | 13.66 |
| B-20974 | 2 | 3–20 | 1.60 | 9.96 | 1.91 | 0.192 | 39.30 | 0.916 | 1.75 | 10.88 | 2.10 | 12.44 | 12.94 |
| B-20975 | 3 | 20–48 | 1.63 | 10.44 | 1.93 | 0.187 | 60.55 | 0.912 | 1.79 | 11.45 | 2.12 | 12.61 | 13.12 |

* Oxides of Mg, Ca, K, and Na.

† Water of combination plus the water equivalent of the bases.

‡ Ignition loss less the organic matter.

§ Water of combination plus the water equivalent of the bases, corrected for the organic matter and carbonate content.

The profile collected 62 miles south of Juarez, Chihuahua, on nearly level topography is described as follows:

*Juarez clay*

1. 0–6 inches, grayish brown clay with finely granular structure in the upper 1-inch layer, followed by fine nut structure below. The material is stiff and only moderately plastic under moist conditions. It is low in organic matter.
2. 6–12 inches, grayish brown clay breaking into medium clods ranging from 1 to 1½ inches in diameter.
3. 12–27 inches, brown crumby clay. This layer contains some carbonates. There is only a gradual transition in texture from the layer above, but there is a sharp transition to a finer texture below, accompanied by a change in color. The structure appears slightly prismatic.
4. 27–36 inches, light reddish brown, crumby clay with large white spots of carbonates. This is the zone of maximum carbonate accumulation.
5. 36–48+ inches, reddish brown stiff calcareous clay. It contains less moisture than the layer above.

A similar profile was collected near the eastern limits of the same laguna near Agua Neuva, about 50 miles north of Chihuahua. This is developed on low level elevations slightly above the laguna basin and bordering the mountain slopes to the east. The cover is a fair stand of short grasses, chiefly grama. The profile is as follows:

*Agua Neuva sandy loam*

1. 0–4 inches, medium gray sandy loam with powderlike structure in the upper one-half inch and fine granular below.
2. 4–10 inches, dark gray, granular sandy loam high in organic matter. Slightly heavier than above.
3. 10–18 inches, dark gray sandy loam with small white spots of carbonates and with fine granular structure. Crushes to a dark yellowish gray.
4. 18–30 inches, light grayish yellow with penetrations of dark gray along root and worm channels and with numerous white accumulations of carbonates. The material is a sandy loam which crushes readily into fine crumbs.
5. 30–42 inches, pale yellow stiff clay or sandy clay highly impregnated with carbonates.
6. 42+ inches, gray crushing to a pale yellowish gray stiff sandy clay, probably waterlaid. High in carbonates.

The relatively high organic content to a depth of 18 inches distinguishes this profile from the regional profile, which is light gray and low in organic matter. The abundance of worm channels, which are rare in most of the soils of this region, suggests a more uniformly high moisture content. This is probably due to added water drained from the adjoining slopes.

Although these two profiles offer some interesting contrasts, they have certain features in common. On this account they are discussed together.

The mechanical analyses are presented in table 1. The soils are not the same in texture; one is a clay, the other is a sandy loam. The first has an average of 60 per cent clay and of 50 per cent colloid and has approximately equal amounts of silt and of very fine sand. In the second profile the textural

relations are reversed. It is sandy, low in silt, and in all but the lowest two horizons the clay and colloid are also low. There is no evidence of extensive translocation of fine material in either profile. The lowest two horizons of both may have been enriched by eluviation, but it is more probable that this textural division of the profile is inherent in the parent material. It is not impossible that the change in texture may mark a change in the depth of an ancient lake. If so, the lower layers were deposited when the lake was deep, and the upper layers when the shore line was near.

The chemical analyses (table 2) of both soils likewise offer no sure evidence of the manner of deposition of parent material, nor do they suggest any marked translocation of material within either profile. They do show, however, that the upper layers of both soils have been leached, particularly in the Agua Neuva soil. The leaching is shown particularly by the removal of calcium carbonate and soluble salts from the upper layers. The Juarez clay is certainly a solonchak soil. The soluble salts are high: 1.26, 1.45, and 1.33 per cent in horizons 3, 4, and 5. They are chiefly chlorides, sulfates, and carbonates. The Agua Neuva sandy loam has 0.32 and 0.48 per cent of soluble salts in the lowest two horizons, but the layers above are relatively free from soluble salts. Leaching has been more thorough in this profile than in the Juarez clay profile, and the pH of 9.3 and 9.7 of the lowest two layers of the Agua Neuva profile are doubtless caused by sodium carbonate. Comparisons of quantities of sodium in the soils with those in the colloid indicate incomplete hydrolysis of the feldspars (see table 3). The greater amount of organic matter in the Agua Neuva soil indicates that the removal of soluble salts from the surface horizon has made it adaptable to a larger number of plants or a greater growth.

The chemical analyses of the colloids (table 3) likewise indicate no material alteration or translocation of the mineral content except sodium. Sodium is low in both soils. It is usually the first to go if leaching takes place. It may be noted, however, that the sodium of the colloids is highest for those horizons in each soil having the most soluble salts and commonly the higher pH (see table 2).

If any changes in the colloids had taken place in the development of the two saline profiles, it would be shown by a comparison of one constituent with another (table 4). The data in each profile are, in general, uniform. No marked differences in various parts of the profiles are indicated. All of the derived data show this uniformity. Slight differences are doubtless accidental or are caused by differences in the composition of the parent material. Be that as it may, the average ratios of silica to sesquioxides and to alumina of the Juarez colloids are 3.99 and 5.25, and the corresponding ratios of the Agua Neuva colloids are 4.68 and 6.26. And a like comparison of water with the sesquioxides and alumina gives ratios of 2.85 and 3.74 for the first, and 3.20 and 4.15 for the second profile. It seems evident that little if any silica has been lost, as compared to alumina, by the more thorough leaching, at a high pH, of the Agua

Neuva profile. Also, the average combined water of the soil acid of the colloid of the Juarez clay is 10.80 per cent and that of the Agua Neuva sandy loam is 11.57. These data show the effect of salinization and desalinization of the soil colloid. Greater leaching of the Agua Neuva profile would have made these differences even greater.

The utilization of the unirrigated desert soils is confined almost entirely to grazing. In many places the insufficiency of supplies of water for stock precludes the use of cattle, and grazing is limited largely to horses, goats, and sheep; in some areas, such as the Bolson de Mapimi, even horses and goats are not to be found, although apparently pasturage is ample. A few areas bordering Rio Grande and its tributaries; Rio del Carmen near Villa Ahumada, Chihuahua; Rio Chuviscar and Rio San Pedro south of the city of Chihuahua in the same state; and Rio Nazas in the vicinity of Torreon, Coahuila, are irrigated and utilized for the production of cotton, corn, small grains, and truck crops. Ninety per cent of the total cotton production of Mexico comes from these regions.

The irrigated districts are densely populated (12) whereas the remainder of the region is sparsely populated. Most of the irrigated soils are light gray silt or clay loams. They are low in organic matter and have a tendency to clod or puddle easily under irrigation. In the Rio Grande Valley attempts have been made to correct these conditions by the addition of fine sand from the adjoining uplands. Some of the irrigation projects have been under tillage for hundreds of years, whereas others, especially in the vicinity of Delicias, Chihuahua, along Rio San Pedro, have only recently been established.

Miscellaneous land types in the same general area include the sand dunes south of Ciudad Juarez, Chihuahua, and the rough, rocky, mountainous slopes, which are, generally speaking, land without soil.

### *Chernozem soils*

An extensive area of dark gray to black soils is developed on the region surrounding Villa Juarez, Tamaulipas. No profiles were taken for laboratory analysis from this region, but certain field observations were made.

A second area of dark gray to black soils is found surrounding Irapuato in the state of Guanajuato and the city of Queretaro to the east in Queretaro. The physiography in this region consists of a series of broad east-west valleys bordered by low mountain ranges. The mountains are capped by lava flows which are dominantly basalt. The soils developed on the mountain slopes are shallow, dark gray to black, and high in organic matter. They are underlain by either caliche or basaltic fragmented materials which are coated with calcium carbonate. The valley soils are heavy black clay to a depth of 6 or more feet. A profile observed 12 miles east of Queretaro, Queretaro, is as follows:

*Queretaro clay*

1. 0–3 inches, black heavy clay with finely granular structure.
2. 3–8 inches, black heavy clay with granular structure. Breaks into irregular clods.

3. 8–30 inches, black heavy clay, which breaks into large prisms 6 to 8 inches in diameter.
4. 30–48 inches, very dark gray to black, smooth, heavy clay.
5. 48–60 inches, very dark gray to black heavy clay.

The profile is on nearly level topography. The present vegetation is short grass. The original vegetation on both the mountain sides and valleys is said to have been small trees, mainly oak, and brush.

In another profile, on level topography in the valley of the Guanajuato south of Irapuato (pl. 1, fig. 1), the upper 28 inches consist of overwash materials, below which dark heavy clay extends to a depth of 97 inches. At this point it is underlain by light gray stiff clay. A description of the profile follows:

*Irapuato clay loam*

1. 0–10 inches, black heavy clay loam crushing to coarse granules. It has numerous perforations, many of which are made by plant roots.
2. 10–23 inches, dark grayish brown silty clay with white carbonate spots. The structure is distinctly laminated above but prismatic below. This layer is penetrated by grass roots.
3. 23–28 inches, brown very fine sandy loam.
4. 28–35 inches, very dark gray clay loam breaking naturally into 4- to 6-inch prisms.
5. 35–55 inches, black heavy clay forming columns similar to those above; calcareous.
6. 55–97 inches, black heavy clay breaking into large cubical clods; calcareous.
7. 97–144 inches, light gray, stiff, calcareous clay with massive structure.
8. 144+ inches, dark red plastic clay.

The soils of this region contrast with certain chernozem profiles observed near Villa Juarez. The dark colored valley soils are at an elevation of approximately 6,000 feet; whereas the soils in the vicinity of Villa Juarez are at elevations of 2,500 feet or less. The former are developed under a rainfall of 400 (15.75 inches) to 800 mm. (31.5 inches); and the latter, under much higher rainfall. The average temperature in the Irapuato region ranges from 59 to 68°F. compared to 77° near Villa Juarez. Although the profiles examined in the Irapuato region are highly calcareous, no definite zone of lime accumulation comparable to that observed in the profile south of Villa Juarez was observed. The dark colored material in the profiles near Irapuato was observed to depths of more than 6 feet; in the vicinity of Villa Juarez the maximum depth of the dark material is approximately 30 inches.

The origin of the dark colored valley soils in the Irapuato region is an interesting question. Inasmuch as parts of these valleys are flooded at intervals of 3 to 5 years, it is possible that the unusual thickness of the dark colored soil is due to the slow accumulation of materials high in calcium carbonate and organic matter from the surrounding mountain sides by slope wash. It is more probable, however, that the soils have literally "swallowed themselves." Partly because of the heavy textures, these soils shrink so much during the long dry periods that wide, deep cracks are formed. Finely granular surface materials are washed or fall into the cracks. This mechanical process operating over a long period would give rise to soils with rather deep, dark solums.

Field observations indicate that the valley soils are low in alkalies. On

drying, the heavy clay surface soil flocculates into coarse granules. This greatly facilitates tillage operations.

Small grains, corn, tomatoes, peppers, and other vegetables are raised on a commercial scale on the dark colored valley soils. Because of the insufficiency of rainfall, most of these crops are raised under irrigation.

The chernozem profile from Irapuato and the profile from Queretaro in many respects closely resemble each other. Certain differences, however, will be noted in the joint discussion of the analytical data (tables 1, 2, 3, 4) of the two soils.

The mechanical analyses (table 1) show the differences in textural character of the two soils. The Queretaro clay profile is very high in clay as well as colloid. The first three horizons of the profile of Irapuato clay loam contain only about one-third as much clay and colloid as do the first two horizons of the profile from Queretaro. But horizons 5 and 6 of the Irapuato profile average a little lower in colloid and clay, and are higher in silt content than the more directly comparable horizons 2, 3, and 4 of the Queretaro soil. In both profiles the two fine sand fractions are low except in the first three horizons of the Irapuato soil. The explanation is simple. The Irapuato soil has been repeatedly flooded by Guanajuato River, which carries large quantities of silt from the slimes of the mines at Guanajuato, which have been operated for more than 200 years. A part of the suspended material in this flood water, added to the natural slope wash, has built up the soil to a depth of 28 or more inches, and a part has probably been carried deeper, as the percolating water penetrates to greater depths of the profile. It seems certain that the first 28 inches are not wholly derived from the same parent material as the soil below (7) although the selenium content indicates that not more than the first 10 inches have been deposited since the operation of the mines began.

The chemical analyses (table 2) likewise show that about 28 inches of the material have been deposited on the original parent material of the Irapuato clay loam. The averages of the silica, magnesium, calcium, and sodium are somewhat higher in the upper part than in the older and deeper part, and the averages of the iron oxide and alumina are lower. The percentage of organic matter decreases from 5.05 in horizon 1 to 0.69 in horizon 3; increases to 1.09 and 1.50 in the next two horizons; and decreases below. Two zones of carbonate accumulation in corresponding parts of the old and new divisions of the profile also occur. The soluble salts, however, have penetrated deeper than 28 inches. They are high in horizons 2, 3, 4, and 5, but are highest in horizons 3 and 4. The soluble salts do not appear to have materially affected the pH of the layers where they are high. In fact, the pH of the top of the buried soil (horizon 4) is 7.8, and the soluble salts are as high as in horizon 3 where the pH is 8.0. The surface layer has a pH of 7.6, but the soluble salts are lower than in horizon 2 where the pH is 8.1. Presumably the material added to the soil is being formed into a new profile, much like the old, in spite of the disturbing effect of the comparatively recent additions.

In many respects the Queretaro profile (table 2) is like the old and the new parts of the Irapuato profile. It is, on the whole, less alkaline, more thoroughly leached of carbonates, and consequently it contains less soluble salts in all all its parts. The somewhat higher percentages of calcium, potassium, and sodium in the first two layers, as compared to horizons 3 and 4, are probably not the result of flooding. These constituents are apparently returned to the upper layers by plants much more rapidly than percolating water could remove them, and a part is certainly still combined in the partially decayed plant residues that have so thoroughly blackened the upper layers of the soil.

The distribution of selenium in the Irapuato soil is largely confined to the first horizon. Its presence in larger amount in this layer suggests that it is furnished chiefly by the additions from the mine slimes (7).

The analyses of the colloids (table 3), except in a few details, are uniform throughout each profile. The colloids of the more recently added first three horizons of the Irapuato soil are, for the most part, somewhat lower in silica and alumina and higher in iron, calcium, potassium, sodium, manganese, phosphorus, sulfur, and organic matter than are those of the deeper and older horizons. The colloids in each part do not differ greatly, as is usual in chernozem profiles (5). Likewise, the colloids of the Queretaro soil do not show marked variation. The similarity of the two chernozem soils is close.

The derived data in table 4 present additional evidence of the conditions just mentioned. The ratios of the various constituents, one or more to another, as well as the combined water and the combined water of the soil acid show the same uniformity mentioned. One of the unusual differences in the Irapuato colloids is the lower ratios of silica to iron oxide and of water to iron oxide in the first three horizons as compared with the deeper horizons. The flood waters have doubtless added this iron to the soil colloid. This is the only evidence that the derived data present of the difference in origin of the two parts of the Irapuato soil.

### *Lateritic soils*

The lateritic soils have certain characteristics strikingly in contrast with those of the chernozems. Red is the dominant color. This contrasts with the dark gray to black colors which prevail in the chernozems. The soil has a high content of organic matter, a pH ranging from neutral to slightly acid, and a smooth texture. This contrasts with the granular surface horizons, low in organic matter, and the highly calcareous, less leached subsoils of the chernozems. These lateritic soils are highly resistant to erosin, whereas the chernozems frequently show evidences of erosion on gentle slopes.

A few miles north of Tamazunchale the surface configuration changes from a relatively smooth plain to deeply dissected topography. Southward from Tamazunchale there is a rapid ascent through mountainous topography for approximately 75 miles. The change in elevation ranges from approximately 5,000 feet at Tamazunchale to 7,300 feet 10 miles beyond Jacala. The pre-

cipitation throughout most of this distance ranges from 2,000 mm. (78.74 inches) to 3,000 mm. (118.11 inches) per annum, and average temperatures range from 68 to 77°F. This is a region of lateritic soils, but certain variations occur.

In an associated intrazonal soil the uppermost 12 inches are black, smooth, highly dispersed clay, and the underlying material is light gray.

The red lateritic soils in this area have been farmed for centuries by the Huastecas Indians. Because of the rugged terrain, these soils are developed on slopes ranging from 45 to almost 100 per cent. Many of the slopes are too steep to allow cultivation and other tillage operations with animal power. Farming operations are accomplished largely by primitive hand tools. Cereals, vegetables, and other subsistence crops are grown. Although numerous exceedingly steep slopes are under cultivation there is very little erosion (pl. 1, fig. 2).

The lateritic soils in this region are developed from Cretaceous limestones.[5] The cover is a dense deciduous forest. A profile (pl. 1, fig. 3) observed 50 miles south of Tamazunchale, on a steep slope, illustrates the regional characteristics.

*Tamazunchale clay*

1. 0–½ inch, surface litter of deciduous tree leaves, mostly oak.
2. ½–3 inches, dark reddish-brown clay with some organic matter.
3. 3–20 inches, red heavy clay, highly dispersed.
4. 20–48 inches, red smooth, heavy clay, highly dispersed.
5. 48+ inches, limestone.

The textural relations of the profile are shown in table 1. The first three horizons represent the residue derived from the fourth horizon of partially disintegrated Cretaceous limestone. As in most soils developed from limestone, these horizons are very high in clay and in colloid. The third layer contains 1 per cent sands, 3.6 per cent silt, and 94.5 per cent clay. The progressive increase in clay content downward suggests that some eluviation has occurred, but the relatively low clay and colloid content is due in part to incomplete dispersion of the dehydrated surface material. Most of the clay in all three horizons has probably remained in place, however, after the removal of calcium carbonate from the limestone by percolating water. Since this soil is developed on extremely steep slopes, a certain amount of erosion, creep, and slumping is apt to occur. Nevertheless, the data do not indicate that such action has occurred to any great extent in the profile examined, and if it has, profile adjustments appear to have been immediate.

The chemical analyses of the soil, table 2, suggest that the limestone residue has also undergone some decomposition and translocation. Silica and titanium decrease and the sesquioxides increase with depth. The complete loss of carbonates shows the thoroughness of the leaching throughout the profile

[5] Based on Geologic Map of Mexico by Willis (23) and Sanchez (19).

horizons. In spite of leaching, the surface horizon has been materially enriched in calcium, as is usual in soils derived from limestones. As a result of this enrichment the surface layer is less acid than the horizon immediately below it or even the one is direct contact with the limestone.

The analyses of the colloids are shown in table 3. The horizons show an increase in silica and alumina from the surface downward. Iron and titanium compounds tend to accumulate in the colloid of the upper layers. Sodium is thoroughly leached from the colloids, but the organic matter has doubtless retained the greater part of the magnesium, calcium, phosphorus, and sulfur in spite of thorough leaching of the profile.

The derived data, table 4, explicitly indicate the character of the colloids of the profile. The ratios show, for the most part, that the colloid is essentially the same for each horizon. The silica-sesquioxide, silica-iron-oxide, and silica-alumina, as well as the iron oxide-alumina, ratios, are low, approximating those of many of the colloids of lateritic soils in the United States. These ratios are about one-half as great as those of the parent material, high in limestone. For the parent material the ratios of silica to the sesquioxides, to the iron oxide, to alumina, and to the bases are 3.34, 25.00, 3.85 and 1.54, respectively. It seems evident that as compared to iron oxide and alumina one-half of the silica of the colloid has been lost in the formation of this colloid. The differences shown in the silica-total base ratios are not significant of large differences in in the soil colloid, since the colloids are so highly leached.

In general the data for this soil are very similar to those reported by Alexander, Edgington, and Byers[6] for soils in the United States which are derived from limestone. These data are also comparable to those of lateritic soils from various parts of the United States (4, 8, 14, 18) that are derived from granite and other parent materials. The soil, then, is a lateritic soil, but the presence of limestone as its base suggests a relationship to the terra rossa soils of Europe, some of which are lateritic red soils.

In view of these comparisons it is evident that the colloid of a soil, whether derived from limestone, granite, or other parent material, eventually has approximately the same composition if leaching, hydrolysis, and other soil-forming processes have been sufficiently active. The order of change is not precisely outlined by the data at hand, but it seems certain that only after the alkalinity is lowered by the complete removal of limestone from the soil by leaching are the remaining silicates destroyed by the same processes, but under more acid conditions, to form a lateritic soil much like the Cecil, Davidson, and others whose parent materials are not limestone.

### *Podzolic and alpine meadow soils*

An interesting soil zonation like that described by Thorp (21) is found on the slopes of the Navado de Toluca, a mountain of volcanic origin 60 miles southwest of Mexico City. The summit, which is capped with snow throughout

[6] A chemical study of some soils derived from limestone. In manuscript, to be published as a U. S. Department of Agriculture Technical Bulletin.

most of the year, reaches an elevation of approximately 15,000 feet. This is 7,500 feet above Mexico City and 6,500 feet above Toluca, which is only a few miles distant. Vegetation ranges from short grass and brush near Toluca through fir on the lower mountain slopes, pine at higher elevations, and grasses above the timber line, to mosses on the nearly barren slopes above.

Soils range from brown soils near Toluca through podzolic soils on the lower mountain slopes and profiles having some features, at least, of podzols (pl. 1, fig. 4) at higher elevations, to alpine meadow soils developed under the grass vegetation above the timber line.

## GENERAL DISCUSSION

The Mexican soils that have been described all have their counterparts in the United States. The similarity applies both to profile development and to chemical character of the colloidal materials. The Torreon profile is similar

TABLE 5

*Review of Derived data*: Mexican soil colloids*

| SOIL TYPE | $\frac{SiO_2}{Fe_2O_3 \cdot Al_2O_3}$ | $\frac{H_2O}{Fe_2O_3 \cdot Al_2O_3}$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{H_2O}{Al_2O_3}$ | $\frac{SiO_2}{\text{TOTAL BASES}^\dagger}$ | COMBINED WATER OF THE SOIL ACID‡ |
|---|---|---|---|---|---|---|
| Torreon sandy clay loam | 3.93 | 2.24 | 4.90 | 2.78 | 6.63 | 9.46 |
| Juarez clay | 3.99 | 2.85 | 5.25 | 3.74 | 4.45 | 10.80 |
| Agua Neuva sandy loam | 4.68 | 3.20 | 6.09 | 4.15 | 4.57 | 11.57 |
| Irapuato clay loam | 3.12 | 2.27 | 3.99 | 2.90 | 7.56 | 11.39 |
| Queretaro clay | 3.41 | 2.31 | 4.15 | 2.81 | 9.66 | 11.03 |
| Tamazunchale clay | 1.61 | 1.89 | 1.92 | 2.26 | 40.08 | 13.24 |

* Profile averages.

† Oxides of Mg, Ca, K, and Na.

‡ Water of combination plus the water equivalent of the bases, corrected for organic matter and carbonate content.

to the Phillips (5) of Montana. The Juarez and Agua Neuva profiles are high in soluble salts like the Fargo (5) of Minnesota. The Irapuato and Queretaro profiles are comparable to the Certe and Hastings (5) in Nebraska and to other chernozem profiles found elsewhere in the United States. The Tamazunchale profile bears a close resemblance to the lateritic Davidson and Cecil (18) and Decatur and Greenville profiles of the southeastern part of the United States.

In order to present certain characteristics of the soil colloids and to indicate the probable clay minerals formed in these soils under certain soil-forming processes, table 5 has been prepared. In this table only the profile averages are presented, since no extreme differences in composition are noted in the complete profiles.

The clay minerals are alumino-silicates that may be formed under a variety of conditions, but under certain comparatively restricted natural conditions they may be obtained pure. Their chemical and physical characteristics are

sufficiently certain to assure their mineralogical identity. The acids of these minerals are assumed to be montmorillonitic acid $6SiO_2 \cdot Al_2O_3 \cdot 3H_2O$, pyrophyllic acid $4SiO_2 \cdot Al_2O_3 \cdot 3H_2O$, halloysitic acid $2SiO_2 \cdot Al_2O_3 \cdot 3H_2O$. In these, iron doubtless more or less replaces alumina.

Because of the similarity of properties it is assumed that the clay minerals are present in soil colloids. Byers (6) has outlined their probable origin in soils essentially as a metathetical reaction between water and orthoclase or certain other reactive minerals. In the soil the soluble products of the reaction are removed by leaching, leaving the residual soil colloid, the composition of which is dependent on the intensity of the reaction and the degree of leaching.

The soils presented have been developed under varied rainfall. Although the character of the parent material, vegetation, and variations in temperature have influenced their formation, differences in the soil colloids may be ascribed chiefly to variations in moisture. Drainage has also modified the kind and character of the soil colloids.

The Torreon sandy clay loam has received the least rainfall of this group of soils, and the colloids throughout this profile might be expected to have been least altered. They are. The ratio of silica to sesquioxides is close to 4, and to alumina it is nearly 5, and the ratios of water to sesquioxides and to alumina are 2.24 and 2.78. The formula ratios then are $3.93\ SiO_2 \cdot Fe_2O_3 \cdot Al_2O_3 \cdot 2.24\ H_2O$; and freed of iron, the ratio is $4.90\ SiO_2 \cdot Al_2O_3 \cdot 2.78\ H_2O$. Iron is doubtless combined, in part at least, in the clay minerals where moisture is limited. The clay mineral in the gray desert soil, therefore, would be expected to approach the formula of pyrophyllic acid, $4\ SiO_2 \cdot Al_2O_3 \cdot 3\ H_2O$. The combined water is low, 9.46 per cent. If no water, then, had been lost by dehydration under desert conditions it would be expected to approach more nearly the theoretical value of 13.6 per cent.

The limited drainage of the saline soils, Agua Neuva sandy loam and Juarez clay, does not permit the free removal of the products of the reaction of the soil minerals and water. Ordinarily, pyrophyllic acid occurs only where there is free drainage. Nevertheless, the ratios of the Juarez clay closely approach the theoretical proportions for pyrophyllic acid if iron is combined in the clay. A little better drainage at high alkalinity in the Agua Neuva sandy loam has caused a loss of alumina in proportion to silica. Theoretical proportions of the three major constituents are therefore not expected.

In the chernozem area the rainfall is greater than that in the area of gray desert soil. This would doubtless cause greater loss of bases and of silica and consequent hydrolysis of the combined iron of the clay, and therefore the clay minerals would be more highly aluminous. They are. Perhaps iron is partially combined, but if not, the formula ratios also closely approach the 4:1:3 ratio of pyrophyllic acid.

For the lateritic Tamazunchale clay, rainfall is more than 100 inches, and extreme hydrolysis would be expected. Free iron oxide is indicated by the color of the soil and of the colloid. Its importance, therefore, in the silicate mineral would be still less than in the chernozems. Again ignoring any com-

bined iron, the formula ratio becomes 1.92 $SiO_2 \cdot Al_2O_3 \cdot 2.26\ H_2O$. The proportions of silica and alumina closely approach the values for halloysitic acid, the combined water is low, 13.24 per cent instead of the theoretical value of 19.6, but dehydration of the clay minerals is expected unless the temperatures are low or other conditions are particularly favorable for water retention.

Differences in the vegetation supported by these soils influence the character of the colloids. But the effects of the vegetation, kind and quantity, are so intimately bound with, and dependent on, the climatic conditions of each area in which one of the great soil groups has developed that the separate evaluation of their importance will not be attempted here. This has been discussed by Kellogg (11). It may be noted, however, that the low rainfall of the desert limits the vegetation of, as well as the removal of the bases from, the gray desert and associated azonal soils. The grasses have maintained the bases in the chernozem soils in spite of a higher rainfall than that found in the desert, but losses do occur. Extremely high rainfall has removed the limestone of the parent material, depleted the bases, caused extreme hydrolysis, and changed the character of the clay minerals of the lateritic Tamazunchale clay. Likewise, the vegetation is different. Instead of the scanty stunted shrub vegetation of the desert soils and the grasses of the chernozems, the lateritic soil favors the growth of coniferous and deciduous trees. Vegetation has its effect in soil formation, but the data at hand do not permit quantitative evaluation.

## SUMMARY

Soil profiles occurring in northern and central Mexico are described. Chemical analyses are given of the soil horizons and their colloids present in six profiles which belong to four of the zonal and intrazonal soils.

These six soils have their counterparts in the United States, with respect to both profile development and character of colloid present.

In Mexico the great soil groups are represented in a comparatively limited area. This is due to the great differences in local relief and the attendant differences in climate and vegetation.

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## PLATE 1

### SOME SOILS OF MEXICO

FIG. 1. Chernozem profile in excavation south of Irapuato, Guanajuato, showing the unusual depth of the dark colored soil.

FIG. 2. Cultivated fields on steep slopes in the laterite soils region south of Tamazunchale, Potosi. Note the absence of gullies and erosion.

FIG. 3. Profile of a laterite soil south of Tamazunchale, Potosi, showing the steep slopes on which the laterite soils are developed, and also the dense forest in this region.

FIG. 4. Profile showing unusually deep organic $A_1$ horizon at an elevation of approximately 13,000 feet on Navado de Toluca. This profile has some of the features of a podzol.

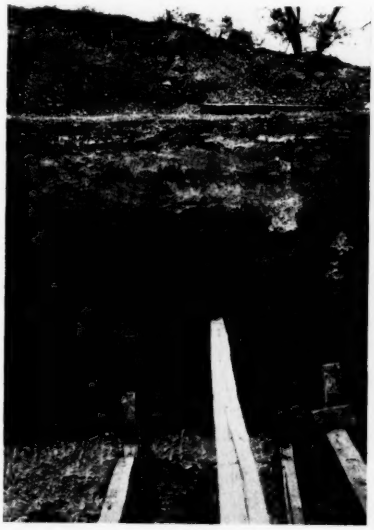

FIG. 1

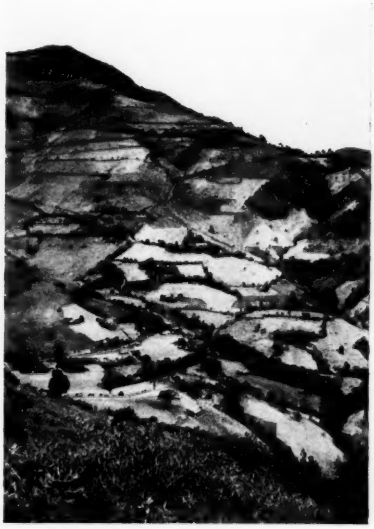

FIG. 2

FIG. 3

FIG. 4

# THE MOVEMENT AND FIXATION OF SUPERPHOSPHATE IN SOILS

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Received for publication June 21, 1938

The application of superphosphate to soils gives rise to several problems, all of which have reference to the profitable utilization of this valuable ingredient. The problems of crop response, uptake by plants, and like matters do not concern us directly in this investigation, which was undertaken primarily to discover what becomes of superphosphate when applied to a soil in its natural state. Such problems as the fixation of phosphate in less soluble forms and the possible loss by leaching will be dealt with as a matter of course, since they have particular reference to the work undertaken in the preparation of this paper.

## REVIEW OF LITERATURE

It is generally accepted that phosphoric acid is not subject to loss by leaching to any important degree. Thus Barker (1) says:

> The movement of water through the soil gradually takes the phosphoric acid deeper into the soil, but the movement is so slow that for practical purposes it may be disregarded, except possibly on a light sandy soil subject to heavy rainfall and where the phosphoric acid is applied in its most soluble form, i.e. ammonium phosphate.

At Rothamsted (13) it is possible to account for nearly all the phosphate added during the last 70 years; some has gone into the crop, and nearly all the remainder is still in the soil, only very small quantities having been washed away. Gardner (9) states that "phosphates do not wash out in the drainage water, and are, therefore, not lost during wet conditions." Weir (19) points out that "movement of phosphorus to lower depths is usually very slow." This appears also to depend on the type of phosphate added, since, as Midgley (12) and later Spencer and Stewart (14) showed, phosphorus applied as disodium phosphate penetrated the soil more readily than did that applied as superphosphate or Ammo-Phos B. Superphosphate, according to Midgley (12), remained mostly in the surface inch of the soil, even after an interval of 6 months.

Stephenson and Chapman (15), however, found that in light- to medium-textured soils an appreciable penetration takes place below the surface foot, though they found little or no penetration to have taken place in very heavy

[1] Publication authorized by the director.

soils. They also found that in nearly all the soils receiving phosphate over a period of years there was a marked accumulation in the surface 6–12 inches. Single heavy applications of a soluble phosphate generally result in deeper penetration than that resulting from frequent small applications. Weidemann (18) pointed out that repeated applications of small amounts of phosphorus failed to increase the amount of available phosphorus in the soil. He also found that about 400 pounds of 20 per cent superphosphate per acre was required to produce a measureable increase in the amount of readily available phosphorus in the soil. That no movement of phosphate takes place except by erosion and crop uptake was the conclusion of Van Alstine (17). Were no movement to take place, obviously a fairly deep application of this ingredient would be advisable to bring it within the root zone. Such would appear to be the case in heavy soils. Midgley (12) found that the total increase of bluegrass resulting from superphosphate worked into the soil was 71.5 per cent greater than that from a mere surface application. Dyer (8), Midgley (12), and others refer to the increased penetration of phosphate when applied in conjunction with certain other salts. This is particularly the case with sodium nitrate, which would thus appear to be of more value when used in conjunction with superphosphate as a top dressing. It may be noted, however, that Brown (4) found no increased penetration resulting from the addition of sodium nitrate with the superphosphate, though the nitrate speeded up the penetration of rock phosphate in an acid soil.

Heck (10) found a penetration of water-soluble phosphorus through 5 inches of silt loam under laboratory conditions. He added, however, that under actual field conditions the same soil would allow much less penetration. It has been noted by Stephenson and Chapman (15) and by Spencer and Stewart (14) that phosphate associated with organic matter penetrates deeper than that in the inorganic form, and the latter writers have demonstrated that certain organic phosphates escape to a marked degree the fixation which occurs with phosphorus applied in some inorganic forms.

Brown (4) found that very little superphosphate remains available in the soil, and none of it penetrates deeper than 2 or 3 inches over 16 years. Rock phosphate applied in the same manner penetrated more than 7 inches. He notes that in most field trials superphosphate, nevertheless, has proved to be the better phosphorus fertilizer. The penetration of rock phosphate is confirmed by Thor (16), who found a marked penetration to a depth of 7–14 inches in a compact soil. Hockensmith, Gardner, and Kezer (11) found that in a calcareous soil triple superphosphate did not penetrate below the depth at which it was placed. Their experiments show that the depth of application makes a marked difference in the yield of alfalfa, 4–6 inches being the optimum depth of application. De Vries and Hetterschij (6), contrary to most other investigators, found fairly considerable penetration and leaching of superphosphate in two representative soil types studied by them.

## PLAN OF STUDY

In laying out an experiment to ascertain the movement and fixation of superphosphate, consideration must be given to soil type, involving mechanical and chemical composition and reaction; to method of application of the superphosphate; and to other factors such as application of water and topographical features.

Of the several distinct soil types existing on the Natal coast, two were selected because of their occurrence on the land allocated to the experiment station, where the work was carried out. Experiment 1 was laid out on dark heavy loam derived from a basic igneous intrusion known as dolerite; and experiment 2, on light sandy loam passing into slightly more compact material. In the latter soil type, at a depth of approximately 1 foot is a layer of pisolitic iron gravel or murram, about 3 inches thick, below which is silty clay, passing into weathering Ecca shale. This soil type, which is very common in the sugar belt, is a very difficult soil to work on. Drainage is poor, and the compact layer of iron gravel (70 per cent $Fe_2O_3$) largely inhibits root penetration. It is believed that the formation of the iron gravel is a result of the leaching down of iron salts. Eventually this layer tends to cement, forming a hard material known as "ouklip."

Each experiment was laid out in three 100-square-foot plots, each of which received a dressing of 800 pounds of superphosphate per acre. This was applied to the surface of plots 1 and 2 and at a uniform depth of 6 inches to plots 3. To effect the applications to plots 3 the soil was removed, replaced, and rolled level. Plots 1 were watered at intervals; plots 2 and 3 were not watered. The experiment thus involved three methods of application: (a) top dressing under irrigation, (b) top dressing without irrigation, (c) covering in—a common method in the planting of sugar cane—without irrigation. Irrigation, if copious immediately after fertilization, would naturally tend to wash the phosphoric acid into the soil. Irrigation in the present experiments, however, was light. This fact would account for its not having produced any significant movement of the phosphoric acid. Crawley (5) found that with immediate irrigation virtually all the phosphorus in a soluble phosphate was left within 6 inches of the surface, and that deferring of the irrigation for 15 hours halved the penetration.

Experiment 1 was studied in four layers; namely, 0–1 inch, 1–3 inches, 3–7 inches, and 7–12 inches. Experiment 2 was studied similarly except that an additional layer containing that of the iron gravel, 12–18 inches, was included. The layer 3–7 inches thus includes the superphosphate dressing of each plot 3. The mechanical composition of the various layers is given in table 1. The estimations were made by the Robinson pipette method with the modification proposed by the writer (2).

The fertilizer was added in a thin uniform layer obtained by weighing out the required portion for each square foot and sprinkling through a wire sieve.

A light application of water was added immediately to settle the fertilizer in case of disturbance by wind. The experiments were laid down in open fields surrounded by a fence, and they were thus exposed to the weather. It is somewhat unfortunate that during the period of this investigation four severe

TABLE 1

*Physical composition of the soils*

| DEPTH OF SOIL SAMPLE | COARSE SAND | FINE SAND | SILT | CLAY | MOISTURE | DISSOLVED MATERIAL | DIFFERENCE* |
|---|---|---|---|---|---|---|---|
| *inches* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| *Experiment 1* | | | | | | | |
| 0–1 | 11.5 | 20.6 | 17.3 | 45.4 | 4.8 | 0.6 | 0 |
| 1–3 | 7.7 | 19.2 | 18.0 | 47.7 | 5.4 | 0.5 | 1.5 |
| 3–7 | 8.1 | 18.2 | 17.4 | 48.0 | 8.3 | 0.5 | 0 |
| 7–12 | 6.6 | 16.6 | 19.3 | 51.0 | 8.0 | 0.7 | 0 |
| *Experiment 2* | | | | | | | |
| 0–1 | 22.7 | 54.6 | 6.2 | 12.1 | 1.9 | 0.3 | 2.2 |
| 1–3 | 19.7 | 56.0 | 6.9 | 12.8 | 2.5 | 0.2 | 1.9 |
| 3–7 | 22.3 | 56.0 | 6.5 | 11.6 | 2.1 | 0.3 | 1.2 |
| 7–12 | 22.8 | 54.6 | 6.2 | 12.4 | 1.6 | 0.2 | 2.2 |
| 12–18 | 47.0 | 30.5 | 4.8 | 14.1 | 4.0 | 0.2 | 0 |

* Including organic matter.

TABLE 2

*Periods of sampling and amounts of rainfall*

| SAMPLES | | DATE OF SAMPLING | INTERVALS BETWEEN SAMPLINGS | TOTAL TIME FROM BEGINNING OF EXPERIMENT | PRECIPITATION | |
|---|---|---|---|---|---|---|
| | | | | | Plot 1* | Plots 2 and 3 |
| | | | *days* | *days* | *inches* | *inches* |
| Immediately on application | | Feb. 22, 1937 | ... | 0 | ..... | ..... |
| Series | 1 | Mar. 8, 1937 | 14 | 14 | 1.33 | 0.23 |
| | 2 | Apr. 2, 1937 | 23 | 37 | 2.84 | 2.04 |
| | 3 | May 7, 1937 | 36 | 73 | 3.69 | 3.69 |
| | 4 | July 2, 1937 | 57 | 130 | 3.56 | 1.66 |
| | 5 | Sept. 13, 1937 | 72 | 202 | 3.96 | 3.21 |
| | 6 | Mar. 5, 1938 | 173 | 375 | 26.97 | 26.82 |
| Total..... | | | | | 42.35 | 37.65 |

* Including 4.70 inches applied.

rainstorms occurred, the precipitation in each case being over 2 inches. Losses due to such erosion are taken into account, however, in the interpretation of results.

Table 2 gives some preliminary information on the experimental work. It

will be noted that in addition to the analyses made immediately after application, six series of analyses were made over a period of 1 year.

## SAMPLING AND METHODS OF ANALYSIS

Samples were taken by cutting away the respective soil layers from the entire length of the plot. Great care was observed in this process, and before each series was taken a section of soil about 8 inches wide was removed to

TABLE 3

*HCl*-soluble $P_2O_5$ in soil of experiment 1 (heavy soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 720 | 1,096 | 1,081 | 1,081 | 1,001 | 941 | 889 | 889 |
| 1–3 | 700 | 700 | 736 | 768 | 760 | 880 | 800 | 780 |
| 3–7 | 664 | 664 | 720 | 720 | 760 | 780 | 760 | 760 |
| 7–12 | 500 | 500 | 536 | 480 | 520 | 480 | 450 | 480 |
| | | | | *Plot 2* | | | | |
| 0–1 | 720 | 1,096 | 1,067 | 1,040 | 1,000 | 800 | 760 | 760 |
| 1–3 | 700 | 700 | 889 | 889 | 800 | 712 | 720 | 752 |
| 3–7 | 664 | 664 | 752 | 680 | 696 | 680 | 660 | 720 |
| 7–12 | 500 | 500 | 432 | 440 | 456 | 480 | 400 | 464 |
| | | | | *Plot 3* | | | | |
| 0–1 | 720 | 720 | 730 | 760 | 740 | 720 | 760 | 720 |
| 1–3 | 700 | 700 | 720 | 720 | 760 | 712 | 736 | 720 |
| 3–7 | 664 | 800 | 800 | 800 | 800 | 800 | 889 | 889 |
| 7–12 | 500 | 500 | 400 | 400 | 384 | 440 | 424 | 464 |

* Sp. gr. 1.115.

† The amount theoretically present in plots 1 and 2, 0–1 inch, is 1,149 p.p.m., and that in plot 3, 3–7 inches, is 781 p.p.m. Both results are guided by the weight of soil (as calculated from the weights of an area 1 foot square), and cannot be strictly accurate.

eliminate any possible contamination of the layers by superphosphate that might have been washed down the sides. The samples were subsampled, air dried, again subsampled, passed through a 1-mm. sieve, and stored away in screw-cap bottles for analysis as soon as possible.

Three determinations were made on each sample; namely, total, available, and water-soluble phosphoric acid.

Total phosphoric acid was determined by refluxing 4 gm. of soil with 40 ml. HCl (sp. gr. 1.115) for 1 hour. Five milliliters of the filtrate was then evaporated

in the presence of calcium acetate solution, ignited, and extracted with 5 ml. of 10 per cent sulfuric acid. Phosphoric acid was determined colorimetrically on this extract. As a check on this estimation, several sodium peroxide fusions were made. The agreement was found to be close. Available phosphoric acid was determined by refluxing 10 gm. of soil with 100 ml. of 1 per cent citric acid for half an hour, igniting, and extracting as above. This procedure replaces the laborious method of shaking the soil in an end to end shaker, and has been found to be equally effectual. Water-soluble phos-

TABLE 4

*Citric*-soluble $P_2O_5$ in soil of experiment 1 (heavy soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 36 | 104 | 100 | 94 | 89 | 90 | 49 | 36 |
| 1–3 | 34 | 34 | 60 | 53 | 36 | 37 | 32 | 34 |
| 3–7 | 36 | 36 | 48 | 48 | 40 | 32 | 28 | 32 |
| 7–12 | 28 | 28 | 36 | 36 | 32 | 31 | 18 | 20 |
| | | | | *Plot 2* | | | | |
| 0–1 | 36 | 104 | 76 | 70 | 92 | 80 | 52 | 37 |
| 1–3 | 34 | 34 | 36 | 33 | 44 | 38 | 34 | 29 |
| 3–7 | 36 | 36 | 31 | 53 | 32 | 30 | 24 | 29 |
| 7–12 | 28 | 28 | 21 | 45 | 35 | 24 | 16 | 17 |
| | | | | *Plot 3* | | | | |
| 0–1 | 36 | 36 | 40 | 46 | 38 | 36 | 34 | 38 |
| 1–3 | 34 | 34 | 40 | 34 | 40 | 40 | 32 | 37 |
| 3–7 | 36 | 88 | 60 | 62 | 52 | 44 | 40 | 40 |
| 7–12 | 28 | 28 | 26 | 37 | 32 | 24 | 16 | 24 |

* One per cent citric acid.

† The amount theoretically present in plots 1 and 2, 0–1 inch, is 455 p.p.m., and that in plot 3, 3–7 inches, is 150 p.p.m.

phoric acid was determined by leaching 100 gm. of soil in a Büchner funnel under vacuum with 500 ml. distilled water. Of this leachate, 100 ml. was evaporated, ignited, and extracted as above. With regard to this estimation, it has to be noted that dilution affects the solubility of soil phosphates. Dukes (7) found that, regardless of soil texture and content of phosphorus, the concentration of phosphorus in the soil solution increases on dilution for a time and then gradually decreases with further dilution. It is estimated that the above process of leaching, carefully controlled to take place in about 15 minutes, removes almost all the water-soluble phosphates.

## RESULTS

The results are given in tables 3–8 in parts per million of $P_2O_5$. A further interpretation will be given to them in a later part of this paper, particularly in respect to the amount of phosphate rendered unavailable by time.

The superphosphate used in these experiments was of extra high grade containing 20 per cent water-soluble, 20.5 per cent citric-soluble, and 21 per cent total $P_2O_5$.

TABLE 5

*Water-soluble $P_2O_5$ in soil of experiment 1 (heavy soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 1.6 | 104.2 | 3.6 | 3.3 | 6.4 | 6.0 | 5.4 | 3.0 |
| 1–3 | 1.6 | 1.6 | 1.7 | 2.0 | 1.5 | 1.2 | 1.3 | 1.8 |
| 3–7 | 1.5 | 1.5 | 1.8 | 1.8 | 1.8 | 1.4 | 1.2 | 2.9 |
| 7–12 | 1.8 | 1.8 | 2.2 | 2.0 | 1.3 | 1.1 | 1.3 | 2.1 |
| | | | | *Plot 2* | | | | |
| 0–1 | 1.6 | 104.2 | 4.7 | 4.0 | 6.6 | 5.6 | 4.0 | 2.2 |
| 1–3 | 1.6 | 1.6 | 1.5 | 2.6 | 1.3 | 0.7 | 1.3 | 2.2 |
| 3–7 | 1.5 | 1.5 | 2.0 | 1.4 | 2.5 | 1.2 | 1.6 | 2.5 |
| 7–12 | 1.8 | 1.8 | 2.0 | 2.8 | 2.7 | 1.0 | 1.4 | 1.3 |
| | | | | *Plot 3* | | | | |
| 0–1 | 1.6 | 1.6 | 1.6 | 1.6 | 1.0 | 0.6 | 1.2 | 1.2 |
| 1–3 | 1.6 | 1.6 | 1.4 | 1.3 | 1.4 | 0.7 | 1.4 | 1.6 |
| 3–7 | 1.5 | 6.0 | 1.8 | 1.8 | 2.2 | 1.8 | 2.8 | 2.1 |
| 7–12 | 1.8 | 1.8 | 1.9 | 0.8 | 1.7 | 1.2 | 1.4 | 1.2 |

† The amount theoretically present in plots 1 and 2, 0–1 inch, is 410.2 p.p.m., and that in plot 3, 3–7 inches, is 112.9 p.p.m.

## INTERPRETATION OF RESULTS

### *Total phosphate*

The first point to be noted about the figures in tables 3 and 6 is that there is a gradual loss of $P_2O_5$ from the surface of the soil. As this is not accumulating in the soil of the next layer, it can safely be stated that the loss is due to erosion. To avoid the unnecessary complications arising from such losses, any future experiments of this nature could wisely be carried out under cover. In both experiments the loss from the plots receiving water is far less than that from the plots not watered during the initial stages. The loss on the dry plots is

almost double that of the watered plots in experiment 1, and it is exactly double in experiment 2. This is undoubtedly due to the bedding of the superphosphate by irrigation. The plots are on almost level ground and were kept free of weeds throughout the year.

That there is no noticeable increase in phosphate in any layer below 1 inch shows definitely that superphosphate does not penetrate the soil to any certain

TABLE 6

*HCl*-soluble $P_2O_5$ in soil of experiment 2 (light soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 400 | 800 | 750 | 730 | 720 | 720 | 680 | 680 |
| 1–3 | 416 | 416 | 416 | 400 | 400 | 384 | 400 | 480 |
| 3–7 | 360 | 360 | 344 | 304 | 320 | 288 | 360 | 400 |
| 7–12 | 240 | 240 | 224 | 208 | 240 | 240 | 240 | 280 |
| 12–18 | 222 | 222 | 200 | 360 | 416 | 400 | 200 | 400 |
| | | | | *Plot 2* | | | | |
| 0–1 | 400 | 800 | 720 | 608 | 560 | 544 | 560 | 560 |
| 1–3 | 416 | 416 | 416 | 384 | 360 | 360 | 400 | 400 |
| 3–7 | 360 | 360 | 328 | 336 | 304 | 304 | 320 | 344 |
| 7–12 | 240 | 240 | 240 | 240 | 272 | 240 | 296 | 224 |
| 12–18 | 222 | 222 | 200 | 256 | 270 | 320 | 200 | 368 |
| | | | | *Plot 3* | | | | |
| 0–1 | 400 | 400 | 360 | 360 | 336 | 364 | 400 | 400 |
| 1–3 | 416 | 416 | 344 | 368 | 352 | 376 | 440 | 416 |
| 3–7 | 360 | 480 | 464 | 400 | 400 | 400 | 480 | 400 |
| 7–12 | 240 | 240 | 320 | 240 | 200 | 200 | 288 | 200 |
| 12–18 | 222 | 222 | 224 | 296 | 376 | 344 | 240 | 336 |

* Sp. gr. 1.115.

† The amount theoretically present in plots 1 and 2, 0–1 inch, is 839 p.p.m., and that in plot 3, 3–7 inches, is 482 p.p.m.

degree. A slight increase may be noted in the 1–3-inch layer in several of the series, but as this is not constant, it may be concluded that such accumulation may have resulted from the phosphate's washing down cracks and fissures. The soil of experiment 1, where this increase is slightly more noticeable, showed many small cracks during dry weather. This accumulation extends, in some instances, down to 7 inches in experiment 1, but no such accumulation occurs in experiment 2 where the soil always remains compact, even though it is very

much lighter in texture and would be expected to have a tendency to retain far less phosphate than the soil of experiment 1. Below 7 inches no phosphate accumulates in experiment 1. In experiment 2 there are occasional abnormal accumulations in the gravel layer, but these are believed to have occurred through lateral infiltration, the phosphate having collected at the base of the experiment between successive samplings. It may be mentioned that in rainy

TABLE 7

*Citric*-soluble $P_2O_5$ in soil of experiment 2 (light soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 75 | 400 | 392 | 200 | 360 | 340 | 200 | 200 |
| 1–3 | 56 | 56 | 80 | 80 | 89 | 89 | 89 | 89 |
| 3–7 | 48 | 48 | 44 | 36 | 48 | 48 | 54 | 89 |
| 7–12 | 24 | 24 | 20 | 18 | 20 | 19 | 64 | 32 |
| 12–18 | 20 | 20 | 14 | 20 | 20 | 16 | 16 | 22 |
| | | | | *Plot 2* | | | | |
| 0–1 | 75 | 400 | 220 | 180 | 160 | 200 | 184 | 200 |
| 1–3 | 56 | 56 | 80 | 89 | 48 | 48 | 48 | 64 |
| 3–7 | 48 | 48 | 40 | 46 | 40 | 40 | 44 | 60 |
| 7–12 | 24 | 24 | 14 | 16 | 20 | 24 | 50 | 26 |
| 12–18 | 20 | 20 | 14 | 16 | 18 | 16 | 24 | 20 |
| | | | | *Plot 3* | | | | |
| 0–1 | 75 | 75 | 50 | 54 | 46 | 46 | 40 | 52 |
| 1–3 | 56 | 56 | 40 | 40 | 48 | 40 | 36 | 52 |
| 3–7 | 48 | 160 | 148 | 110 | 83 | 80 | 89 | 69 |
| 7–12 | 24 | 50 | 52 | 20 | 18 | 24 | 21 | 20 |
| 12–18 | 20 | 20 | 20 | 16 | 16 | 16 | 16 | 16 |

* One per cent citric acid.

† The amount theoretically present in plots 1 and 2, 0–1 inch, is 504 p.p.m., and that in plot 3, 3–7 inches, is 167 p.p.m.

weather this gravel layer conducts a considerable amount of seepage water. This seepage was noted in the experimental plots. The conclusion drawn from this analytical work is that superphosphate does not penetrate below 1 inch, except in instances where ingress takes place through fissures in the soil. A further conclusion to be drawn is that superphosphate buried in the soil at a depth of 6 inches is not moved by soil water, as no loss takes place over 1 year from the layer sampled, namely, 3–7 inches.

The small variations occurring from one series to another are thought to be principally due to local variations in soil composition.

### *Citric-soluble phosphate*

The study of available phosphate afforded an approximate means of distinguishing between loss of availability due to experimental procedure and that due to time. Far greater significance, of course, should be attached to

TABLE 8

*Water-soluble $P_2O_5$ in soil of experiment 2 (light soil type)*

Results expressed in parts per million of soil

| DEPTH | BEFORE APPLICATION | IMMEDIATELY AFTER APPLICATION† | SERIES 1, AFTER 14 DAYS | SERIES 2, AFTER 37 DAYS | SERIES 3, AFTER 73 DAYS | SERIES 4, AFTER 130 DAYS | SERIES 5, AFTER 202 DAYS | SERIES 6, AFTER 375 DAYS |
|---|---|---|---|---|---|---|---|---|
| *inches* | | | | | | | | |
| | | | | *Plot 1* | | | | |
| 0–1 | 2.5 | 250.0 | 40.0 | 20.0 | 19.0 | 18.0 | 16.7 | 13.9 |
| 1–3 | 1.5 | 1.5 | 2.7 | 2.1 | 2.2 | 2.0 | 1.8 | 3.2 |
| 3–7 | 1.9 | 1.9 | 1.7 | 1.4 | 1.3 | 1.0 | 1.0 | 2.2 |
| 7–12 | 1.1 | 1.1 | 1.4 | 1.0 | 0.8 | 0.9 | 0.9 | 1.7 |
| 12–18 | 1.2 | 1.2 | 0.9 | 0.8 | 0.6 | 0.9 | 0.7 | 0.6 |
| | | | | *Plot 2* | | | | |
| 0–1 | 2.5 | 250.0 | 27.8 | 13.0 | 7.2 | 8.0 | 14.3 | 11.9 |
| 1–3 | 1.5 | 1.5 | 2.4 | 1.2 | 0.8 | 0.9 | 1.0 | 1.8 |
| 3–7 | 1.9 | 1.9 | 2.1 | 1.4 | 0.9 | 1.0 | 0.9 | 1.2 |
| 7–12 | 1.1 | 1.1 | 1.1 | 1.0 | 0.8 | 0.9 | 0.8 | 1.2 |
| 12–18 | 1.2 | 1.2 | 0.8 | 0.6 | 0.6 | 0.9 | 0.9 | 0.9 |
| | | | | *Plot 3* | | | | |
| 0–1 | 2.5 | 2.5 | 1.6 | 0.9 | 1.0 | 1.0 | 1.1 | 1.6 |
| 1–3 | 1.5 | 1.5 | 1.4 | 0.9 | 0.8 | 0.9 | 1.0 | 1.5 |
| 3–7 | 1.9 | 17.0 | 8.0 | 7.0 | 5.0 | 6.9 | 7.0 | 4.2 |
| 7–12 | 1.1 | 1.1 | 1.6 | 1.0 | 1.4 | 1.8 | 1.2 | 1.8 |
| 12–18 | 1.2 | 1.2 | 1.3 | 0.8 | 1.0 | 0.9 | 0.9 | 1.2 |

† The amount theoretically present in plots 1 and 2, 0–1 inch is 420.6 p.p.m., and that in plot 3, 3–7 inches, is 118.1 p.p.m.

fixation with time, since the experimental procedure creates optimum conditions for chemical (and physical) reaction which would not normally take place in the field. This is a fact generally disregarded in soil study, perhaps justly, since the difficulty is one which cannot readily be overcome. In experiment 1, 0–1 inch, 84 per cent of the loss of availability takes place immediately on application, and in the same layer of experiment 2, 24 per cent. In the 3–7-inch layer of experiment 1, this amounts to 54 per cent, and in the same layer

of experiment 2, it amounts to 6 per cent. The loss is roughly proportional to the clay content, as would be expected. The loss in the 3–7 inch layer is not entirely proportional to the loss in the 0–1-inch layer, probably on account of the different ratio of soil to phosphate solution, the 3–7-inch soil layer being four times as thick as the 0–1-inch layer for the same quantity of phosphate. These losses have, of course, taken place entirely during the analytical procedure and will have to be allowed for. The attempt to account for the loss of available phosphate in plots 1 and 2 and thereby the actual amount fixed in the soil was made by eliminating the two disturbing factors: first, mechanical transportation from the experiments by rainwater, wind, etc.; and second, amount of phosphate fixed in process of estimation. The assumption was that all the total phosphate lost was in the available form, since almost all the total phosphoric acid is in the available form in superphosphate.

The amount lost by mechanical means is easily determined, but the attempt to differentiate between the amounts fixed by process and by time was found to be impracticable. In plots 3, where the fertilizer was buried, less difficulty was experienced, as the complications arising out of mechanical losses did not occur.

As the subject of phosphate fixation comes to the fore in a consideration of the available phosphate left in the soil, reference to the writer's method of estimating phosphate fixation (3) is in order. This experimental procedure was adopted in attempting to ascertain fixation in the various series by adding to the control sample the amount of available phosphate estimated to be present for each series. The procedure is briefly as follows: 10 gm. of soil is refluxed with 100 ml. of 1 per cent citric acid containing 4 mgm. $P_2O_5$ (as di-ammonium phosphate) for half an hour, and the amount of $P_2O_5$ in solution is determined. From this is deducted the quantity of $P_2O_5$ soluble in 1 per cent citric acid alone by the same process. The remainder, deducted, in turn, from the amount of available $P_2O_5$ originally applied, gives the amount fixed in process.

In plot 3, the amount of available phosphate fixed by process could be arrived at by subtracting the amount immediately after application from the amount of phosphate originally present and added. If it is assumed that this will remain constant throughout the experiment, the amount fixed by time can be determined. Table 9 gives the results of this procedure.

From this table it may be noted that although the lighter soil has only about one-ninth of the fixing power of the heavier soil, the fixation occurs much more rapidly in the lighter soil. This is because initially almost twice as much phosphate is left available for fixation by time in the lighter soil.

The soil layers in both experiments were weighed and calculated to pounds per acre. The figures of series 6 in table 9, multiplied by 1.437, for experiment 1, and by 1.381, for experiment 2, will give the amounts fixed by time in pounds per acre 4-inch (3–7 inches).

Some objection to the final results of table 9 still remains. Since fixation

takes place with time, the available phosphate will decrease, and consequently the assumed constant amount fixed in process will probably decrease as well. The amounts fixed by time then would be too low and still not sufficiently representative of the degree of fixation by time. Table 9 shows, however, that a considerable part of the superphosphate buried in the soil remains available. It would appear from table 4 that all the fertilizer applied on the heavy type of soil has been fixed, but the fact that a large proportion can be fixed by process alone, throws doubt on such an assumption.

With respect to top dressing, unfortunately, little can be said, but it can be concluded that on sandy loam after 1 year, there still remains a considerable amount of available phosphate, whether applied in the drill or on the surface.

TABLE 9

*Fixation of phosphate by time in soils of experiments 1 and 2*

Results expressed in parts per million of soil

| SERIES | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period of time | After 14 days | | After 37 days | | After 73 days | | After 130 days | | After 202 days | | After 375 days | |
| Experiment | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Available $P_2O_5$ added and present | 150 | 167 | 150 | 167 | 150 | 167 | 150 | 167 | 150 | 167 | 150 | 167 |
| Available $P_2O_5$ found | 60 | 148 | 62 | 110 | 52 | 83 | 44 | 80 | 40 | 89 | 40 | 69 |
| Available $P_2O_5$ fixed by process and by time | 90 | 19 | 88 | 57 | 98 | 84 | 106 | 87 | 110 | 78 | 110 | 98 |
| Available $P_2O_5$ fixed by process* | 62 | 7 | 62 | 7 | 62 | 7 | 62 | 7 | 62 | 7 | 62 | 7 |
| Available $P_2O_5$ fixed by time | 28 | 12 | 26 | 50 | 36 | 77 | 44 | 80 | 48 | 71 | 48 | 91 |

* Obtained by deducting the amount of available $P_2O_5$ immediately after application from the amount of available $P_2O_5$ added and originally present.

### *Water-soluble phosphate*

In experiment 1 all the citric-soluble phosphate remained water soluble in the process of estimation. A very rapid fall, however, is noted after 14 days, when the figure has reached its equilibrium. Thereafter for a year it varies only slightly. When the superphosphate is buried in the sand, almost all the phosphate is rendered insoluble in the process of estimation. This is very remarkable, as the experimental procedure involves only a 10–15 minute leaching of the soil with water; it goes to show the extreme rapidity with which phosphoric acid is absorbed by a clayey soil. After 14 days, no water-soluble phosphoric acid could be estimated in the soil. How much of this fixation is due to process and how much to time, it is not possible to say. An indication of the amount fixed by process can be obtained by reference to the quantity fixed immediately after application where process alone is the factor.

The lighter soil of experiment 2 was able to absorb less than half the water-soluble phosphoric acid in process, and an appreciable amount still remained after 14 days. After one year there was still about six times the original

amount of water-soluble phosphate found before application. The water-soluble phosphoric acid of buried superphosphate decreased very markedly in process, and after a year only about twice the original quantity was obtained.

If any movement of water-soluble phosphoric acid occurs, it is very slight. There is no penetration below the first inch in heavy soils, and only a very slight and erratic penetration in light soils.

These results show that in heavy soils after the application of 800 pounds per acre superphosphate, whether as a top dressing or in the drill, we cannot expect to find experimentally any water-soluble phosphoric acid at the end of a year. On lighter soils a small quantity remains unabsorbed, but such a statement would not be strictly accurate for fertilizer buried in this soil. It must be borne in mind, however, that though the results of experimental work show these to be the facts, greater quantities, nevertheless, occur in the soil in its undisturbed state. An attempt to estimate these quantities was made in the instance of available phosphate, but the only true indicator is the plant itself. That the citric-soluble and water-soluble phosphoric acid was rapidly absorbed by time has, nevertheless, been sufficiently demonstrated in these experiments.

## SUMMARY AND CONCLUSIONS

A study was made of the movement and fixation of superphosphate under field conditions in two distinct soil types. This was ascertained by applying superphosphate as top dressing under irrigation, as top dressing without irrigation, in the drill and buried.

The study was conducted over one year, samples being taken at six intervals after application.

In these samples, total, citric-soluble, and water-soluble phosphoric acid were estimated.

The conclusions drawn from this work are as follows:

Erosion of total phosphate from surface dressings is considerable, being greater in the heavier soil type. In both soil types this has been very greatly reduced by watering. Movement of total phosphoric acid cannot be traced appreciably below the first inch from the surface, even in the lighter soil. Occasional penetration appears to take place in fissures. In neither the heavier nor the light soil has any loss from the buried superphosphate occurred. No movement below (or above) can be detected in the buried fertilizer.

Before results were interpreted an attempt was made to eliminate the effect of fixation by experimental procedure. This was not altogether satisfactory, but warranted the drawing of the following conclusions:

The fixation by analytical process in a heavy soil type is so much greater than that in a light soil as, perhaps, to obscure the results obtained. As a result, the fixation with time in a light soil stands out more clearly than that in a heavy type, although a heavier fixation in the heavy type actually takes place.

Watering tends to prolong somewhat the availability of phosphate.

Water-soluble phosphate is lost in considerable amounts in process of estimation in a heavy soil type, and in appreciable amounts in a lighter type. After 14 days virtually all the water-soluble phosphate has vanished from the heavy soil, but at the end of a year some still remains in the light soil, the loss being very gradual. In a heavy soil type the increase in water-soluble phosphate, due to applications of 800 pounds superphosphate per acre, is almost negligible, whether the dressing be applied in the soil or on the surface.

The fact that analytical results with respect to phosphate fixation can be very misleading if interpreted literally has been illustrated. Since the experimental procedure itself plays a disturbing part, such figures do not necessarily reflect conditions prevailing in the soil.

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# ACTION OF CARBON DIOXIDE ON SOILS

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Received for publication August 12, 1937

Carbon dioxide plays an important rôle in the economy of nature. Not only is it the means of transport of carbon from one place to another, but by its acidic character it causes the movement of minerals, the weathering of rocks, and the release of plant nutrients from the soil. The reaction of natural soils, especially that of highly alkaline soils in which the pH value is entirely governed by the carbonate-bicarbonate ratio (3), is greatly modified by its buffer action. It is therefore of interest to study the action of $CO_2$ on soils with particular reference to the nature and amount of exchangeable bases in them.

Two things seemed important in such an investigation: the control of the partial pressure of $CO_2$ and the control of the nature and amount of exchangeable bases. The former was accomplished by the help of gas meters, and the latter by simply neutralizing an unsaturated soil with different bases up to various pH values. Air containing varying amounts of $CO_2$ was passed through the soil suspensions held in a funnel with a sintered glass disk. The air containing $CO_2$ was forced from the bottom, which kept the suspension well stirred. Preliminary observations showed that the results with $CO_2$-air mixtures of varying composition were erratic. The nature of the substances involved and the experimental technic do not admit of a graded reaction capable of measurement. Two standards were, therefore, adopted; namely 1 per cent $CO_2$ and 100 per cent $CO_2$. The results recorded in this paper refer only to these concentrations.

## ACTION OF $CO_2$ ON THE SOLUBLE SALTS AND ON THE pH VALUE OF SOILS

The main effect of $CO_2$ on soils, and the one that is of greatest interest from the practical point of view, is associated with alterations in the soluble salts and in the pH values. Twenty-five soils were used for this study. Only $CO_2$ was passed through the suspension, which had a soil-water ratio of 1:10. The pH values were determined with the glass electrode. The results, given in table 1, show that the soluble salts increased and the pH value decreased. The extent of the change seems to be different for different soils. The ratio of the pH values before and after the passage of $CO_2$ is, however, fairly constant (approximately 0.7) but is slightly higher for soils containing no $CaCO_3$ than for calcareous soils. The ratio of soluble salts before and after $CO_2$ treatment is not constant. There is some indication, however, that this ratio is higher

for carbonate-free soils than for those containing $CaCO_3$. If the lowering of the pH value is partly due to an increase in the soluble salts (1), then a certain degree of parallelism between the two ratios is comprehensible. The effect of $CO_2$ on soluble salts is similar to that of soils. Results with a few salts are

TABLE 1

*Effect of $CO_2$ on pH and on soluble salts of soils*

| SOIL P.C. | CLAY 0.002 MM. | CARBONATE | INITIAL pH ($pH_1$) | pH AFTER PASSAGE OF $CO_2$ ($pH_2$) | $\frac{pH_2}{pH_1}$ | SALTS BEFORE PASSAGE OF $CO_2$ ($S_1$) | SALTS AFTER PASSAGE OF $CO_2$ ($S_2$) | $\frac{S_2}{S_1}$ |
|---|---|---|---|---|---|---|---|---|
| | *per cent* | *per cent* | | | | | | |
| 1 | 11.30 | 34.25 | 8.08 | 5.70 | 0.70 | 0.26 | 0.75 | 2.88 |
| 2 | 59.35 | 5.0 | 7.90 | 5.64 | 0.71 | 0.42 | 0.66 | 1.57 |
| 3 | 62.2 | 0.5 | 7.37 | 5.22 | 0.70 | 0.078 | 0.40 | 5.12 |
| 4 | 15.2 | 1.0 | 8.48 | 5.6 | 0.66 | 0.11 | 0.5 | 4.54 |
| 5 | 12.3 | 1.87 | 8.8 | 5.9 | 0.67 | 0.078 | 0.66 | 8.46 |
| 6 | 28.4 | 0.0 | 5.42 | 4.25 | 0.78 | 0.26 | 0.70 | 2.69 |
| 7 | 21.8 | 6.5 | 9.46 | 5.8 | 0.61 | 0.93 | 1.8 | 1.93 |
| 8 | 25.2 | 0.75 | 7.7 | 4.7 | 0.61 | 0.13 | 0.44 | 3.38 |
| 9 | 21.6 | 0.0 | 5.6 | 4.4 | 0.78 | 0.084 | 0.15 | 1.78 |
| 10 | 35.6 | 1.12 | 7.9 | 5.2 | 0.65 | 0.198 | 0.73 | 3.68 |
| 11 | 32.8 | 2.5 | 7.5 | 5.2 | 0.69 | 0.18 | 0.93 | 5.16 |
| 12 | 7.2 | 0.0 | 5.9 | 4.1 | 0.69 | 0.27 | 0.36 | 1.33 |
| 13 | 58.9 | 1.5 | 7.5 | 5.0 | 0.66 | 0.16 | 0.54 | 3.37 |
| 14 | 21.5 | 0.0 | 5.57 | 4.8 | 0.86 | 0.05 | 0.18 | 3.60 |
| 15 | 22.4 | 0.25 | 7.14 | 5.1 | 0.71 | 0.28 | 0.45 | 1.60 |
| 16 | 8.7 | 1.87 | 7.6 | 5.35 | 0.70 | 0.20 | 0.66 | 3.30 |
| 17 | 14.1 | 0.5 | 7.3 | 4.8 | 0.65 | 0.30 | 0.49 | 1.63 |
| 18 | 22.6 | 0.12 | 5.62 | 4.48 | 0.79 | 0.09 | 0.15 | 1.66 |
| 19 | 42.6 | 1.0 | 7.27 | 5.22 | 0.71 | 0.22 | 0.44 | 2.00 |
| 20 | 8.1 | 0.12 | 5.74 | 4.32 | 0.75 | 0.07 | 0.14 | 2.00 |
| 21 | 13.5 | 2.87 | 7.2 | 5.4 | 0.75 | 0.22 | 0.68 | 3.09 |
| 22 | 15.1 | 0.12 | 5.9 | 4.74 | 0.80 | 0.11 | 0.23 | 2.09 |
| 24 | 9.7 | 1.75 | 7.32 | 5.42 | 0.74 | 0.13 | 0.82 | 6.30 |
| 25 | 4.0 | 0.0 | 5.8 | 5.8 | 1.0 | 0.05 | 0.29 | 5.80 |
| 26 | 22.5 | 0.0 | 6.4 | 5.8 | 0.79 | 0.16 | 0.29 | 1.81 |
| Sodium acetate..... | | | 7.6 | 5.77 | 0.75 | .... | .... | .... |
| Sodium biborate..... | | | 8.86 | 6.66 | 0.75 | .... | .... | .... |
| Sodium urate..... | | | 8.92 | 6.64 | 0.74 | .... | .... | .... |
| Sodium carbonate..... | | | 10.7 | 6.92 | 0.65 | .... | .... | .... |

included in table 1, and the ratio $pH_2/pH_1$ is of the same order as in the case of soils.

## ACTION OF $CO_2$ ON SINGLE-BASE SOILS

Single-base soils were prepared by treating a completely unsaturated soil with increasing quantities of various hydroxides. Carbon dioxide was passed

through suspensions of these soils. The results are given in table 2. It is seen that Na-soil is not flocculated by $CO_2$. This point will be discussed more fully later. At the lower pH values the flocculation is only partial. The ratio $pH_2/pH_1$ decreases as the original pH increases irrespective of the nature of the exchangeable base in the soil.

TABLE 2

*Action of $CO_2$ on single-base soils at various pH levels*

| SOIL | INITIAL pH ($pH_1$) | pH AFTER PASSAGE OF 1 PER CENT $CO_2$ | pH AFTER PASSAGE 100 PER CENT $CO_2$ ($pH_2$) | FLOCCULATION* | pH AFTER ADDITION OF $CaCO_3$ | pH AFTER PASSAGE OF $CO_2$ | $\frac{pH_2}{pH_1}$ |
|---|---|---|---|---|---|---|---|
| *m.e./100 gm.* | | | | | | | |
| K-Soil: | | | | | | | |
| 39 | 5.75 | 5.55 | 5.18 | F | 6.45 | 5.83 | 0.90 |
| 51 | 7.2 | 5.8 | 5.6 | F | 6.6 | 6.27 | 0.77 |
| 77 | 9.83 | 6.8 | 6.06 | F | 7.55 | 6.53 | 0.61 |
| Na-Soil: | | | | | | | |
| 20 | 4.32 | 4.32 | 4.24 | X | 7.08 | 6.26 | 0.98 |
| 48 | 6.7 | 7.1 | 5.5 | X | 7.82 | 6.2 | 0.82 |
| 72 | 9.25 | 6.27 | 6.03 | X | 6.95 | 6.28 | 0.65 |
| Ca-Soil: | | | | | | | |
| 34 | 3.94 | 3.83 | 3.82 | PF | No $CaCO_3$ added to | | 0.96 |
| 56 | 5.97 | 5.8 | 5.8 | F | calcium soil | | 0.97 |
| 96 | 9.6 | 6.8 | 6.1 | F | | | 0.63 |
| Mg-Soil: | | | | | | | |
| 34 | 5.5 | 4.5 | 4.6 | PF | 5.02 | 4.78 | 0.83 |
| 56 | 7.06 | 6.35 | 5.47 | F | 7.15 | 5.7 | 0.77 |
| 100 | 8.2 | 6.6 | 5.9 | F | 7.8 | 6.4 | 0.71 |

* F = flocculated; PF = partly flocculated; X = no flocculation.

## RÔLE OF $CO_2$ IN THE RECLAMATION OF ALKALI SOILS

The action of $CO_2$ on soils at once raises the question of the rôle of $CO_2$ in the reclamation of alkali soils. Alkali soils, as is well known, have the following characteristics:

High exchangeable Na as compared to other bases, especially Ca.
High pH value.
A state of deflocculation or dispersion.

Reclamation of such soils naturally brings about a change in the reverse direction. We shall therefore see to what extent these changes can be brought about by $CO_2$ in soils of varying degrees of alkalinity. Calcium carbonate is an important constituent of the majority of alkali soils; the action of $CO_2$, therefore, was studied with and without $CaCO_3$.

Soils of varying degrees of alkalinity at different pH levels were prepared by neutralizing the H-soil with varying quantities of $Ca(OH)_2$-NaOH mixtures of appropriate strength. The results are expressed in terms of the percentage

of sodium in the total bases (Ca + Na) present in each soil and are given in table 3. The following conclusions regarding the action of $CO_2$ on soils are drawn as a result of this study.

There is a substantial decrease in the pH values at all degrees of alkalinity, as indicated by the percentage of NaOH in the mixtures of hydroxide.

At low pH values flocculation occurs at all degrees of alkalization. When the pH value is high, flocculation fails to take place at degrees of alkalinity higher than 60–80 per cent.

In the presence of $CaCO_3$ a large quantity of exchangeable Na is brought into solution which could be leached out, resulting in a substantial reduction in the degree of alkalization.

TABLE 3

*Effect of $CO_2$ on soils of different degrees of alkalinity*

| NaOH | $Ca(OH)_2$ | DEGREE OF ALKALINITY | INITIAL pH ($pH_1$) | pH AFTER PASSAGE OF 1 PER CENT $CO_2$ | pH AFTER PASSAGE OF 100 PER CENT $CO_2$ ($pH_2$) | FLOCCULATION* | pH AFTER ADDITION OF $CaCO_3$ | pH AFTER PASSAGE OF $CO_2$ | $\frac{pH_2}{pH_1}$ |
|---|---|---|---|---|---|---|---|---|---|
| *m.e./100 gm.* | *m.e./100 gm.* | *per cent* | | | | | | | |
| 0 | 12 | 0 | 5.80 | 6.02 | 5.2 | F | .... | .... | 0.89 |
| 1.6 | 6.4 | 20 | 5.86 | 5.67 | 5.26 | F | 6.58 | 5.77 | 0.89 |
| 3.2 | 4.8 | 40 | 5.86 | 5.86 | 5.4 | F | 6.47 | 5.86 | 0.92 |
| 4.8 | 3.2 | 60 | 5.95 | 5.8 | 5.4 | F | 6.4 | 5.85 | 0.90 |
| 6.4 | 1.6 | 80 | 6.0 | 5.86 | 5.25 | F | 7.0 | 6.0 | 0.87 |
| 8 | 0 | 100 | 6.5 | 5.5 | 5.25 | F | 6.9 | 5.9 | 0.80 |
| 0 | 18 | 0 | 6.0 | 6.38 | 5.02 | ... | .... | .... | 0.83 |
| 3.2 | 12.8 | 20 | 6.2 | 5.55 | 5.4 | F | 6.32 | 5.85 | 0.87 |
| 6.4 | 9.6 | 40 | 6.4 | 6.2 | 5.4 | PF | 6.38 | 6.0 | 0.84 |
| 9.6 | 6.4 | 60 | 6.4 | 5.7 | 5.5 | PF | 6.43 | 5.87 | 0.85 |
| 12.8 | 3.2 | 80 | 6.6 | 5.36 | 4.58 | PF | 6.28 | 5.8 | 0.69 |
| 16 | 0 | 100 | 7.33 | 5.06 | 4.62 | PF | 6.38 | 5.9 | 0.63 |
| 0 | 50 | 0 | 8.3 | 7.55 | 5.8 | F | .... | .... | 0.69 |
| 8 | 32 | 20 | 8.6 | 7.5 | 5.6 | F | 6.9 | 5.8 | 0.65 |
| 16 | 24 | 40 | 8.8 | 6.17 | 5.6 | F | 6.6 | 5.8 | 0.63 |
| 24 | 16 | 60 | 9.1 | 7.35 | 5.78 | PF | 6.8 | 6.1 | 0.63 |
| 32 | 8 | 80 | 9.35 | 6.75 | 6.1 | PF | 7.54 | 5.9 | 0.65 |
| 40 | 0 | 100 | 9.5 | 6.5 | 6.0 | X | 7.2 | 6.18 | 0.64 |

* F = flocculated; PF = partly flocculated; X = no flocculation.

The laboratory results are substantiated by a number of field observations on alkali soils. It was found that in a rice field the pH values of soil samples taken from near the roots were lower by more than 1 pH unit than that of the soil taken from some distance away. Similar results were obtained in a field under grass.

The importance of $CaCO_3$ in the reclamation of alkali soils is well brought out. These results are in agreement with the observations of Puri et al. (2), who showed that the movement of $CaCO_3$ in alkali soils causes their regeneration or reclamation. Calcareous soils are, therefore, more easily reclaimed than are carbonate-free soils.

Smith and co-workers have presented data (4) which apparently tend to show that $CO_2$ may result in an increased pH value of the soil solution, depending upon the soil type. Their results would seem to contradict our observations, in which we have consistently found a lowering of the pH value as a result of the action of $CO_2$. The experimental technic of these authors was entirely different from ours. They used soil in plots to which $CO_2$-saturated water was added or to which $CO_2$ was passed from below at the rate of 5 liters an hour for 1 hour each day throughout the experiment, which extended over several months. It was therefore not entirely the effect of $CO_2$ that was being measured, but the cumulative effect of several factors not entirely under control. A solution of $CO_2$ in water has a pH value of about 4; it is therefore bound to decrease the pH value of a soil on coming in contact with it. Secondary charges, which might raise the pH value, must take place, however, in the course of time.

## SUMMARY

The action of $CO_2$ on soils has been studied by following the changes in the pH values.

The importance of $CO_2$ in the reclamation of alkali soils is well brought out by the observation that $CO_2$ induces changes that are the reverse of alkalization.

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# COENZYME R REQUIREMENTS OF RHIZOBIA

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Received for publication June 6, 1938

In previous publications (1, 2, 3, 7) from this laboratory it was shown that certain, but not all, species of *Rhizobium* require addition of the accessory growth substance, coenzyme R, in order for good growths to occur. Most strains of *Rh. trifolii*, *Rh. leguminosarum*, *Rh. meliloti*, and *Rh. phaseoli* tested show a 20- to 80-fold increase in growth within 4 to 6 days following additions of 0.5 to 1 p.p.m. of our more concentrated preparations. Organisms of the cowpea, soybean, and lupine groups usually make only a very limited response. Although the chemical and physiological studies strongly indicate that the growth response is due to one substance, it is possible that a group of substances, having similar chemical properties, may act as the essential factor.

Several investigators, especially Thorne and Walker (10), Clark (6), and McBurney, Bollen, and Williams (8), have confirmed these findings in major part at least. More recently, however, Thorne and Walker (11) reported data from which they concluded that "no evidence was found which indicates that the root nodule bacteria require any complex, unidentified substances for their growth. Many materials, however, are able to stimulate the growth and respiration of these organisms in mineral salts-sucrose c.p. media with $KNO_3$, $NH_4Cl$, or asparagin employed as sources of nitrogen." They arrived at this conclusion even though they obtained scarcely any growth of *Rh. trifolii* in a medium containing c.p. sucrose and potassium nitrate, but did obtain a 46-fold growth increase within 2 days after the addition of an alcoholic extract of commercial cane sugar, which, as Allison and Hoover (1) showed previously, contains coenzyme R in considerable quantities. With asparagin the total growth was greater, although the increase over the control was less, probably because of the trace of growth factor that is usually present as an impurity in asparagin unless it has been carefully recrystallized.

Thorne and Walker reported also that *Rh. meliloti* and *Rh. trifolii*, although unable to make good growths for several consecutive transfers on a c.p. sucrose-nitrate medium, were able to do so if asparagin or ammonium chloride was substituted for the nitrate. Furthermore, if small quantities of the reducing substances, cysteine or thioglycollic acid, were added to the nitrate medium,

[1] The writers are much indebted to Sam R. Hoover for his numerous suggestions given during the course of these investigations, and to C. A. Ludwig and Dean Burk for their valuable criticisms of the manuscript.

growth was satisfactory. Ferric chloride was also beneficial. They interpreted these results to mean that the inability of the rhizobia to make good growths for several transfers in the c.p. sucrose-nitrate-inorganic salts medium previously used in our laboratory is due to (*a*) deficient iron and (*b*) too high an oxidation-reduction potential in the presence of potassium nitrate. In our previous papers (1, 2, 3) special attention was given to iron, since we originally suspected that the accessory growth factor was available iron. It was concluded (2) that "the iron requirements of rhizobia are small. The stimulating effect of additions of available iron was usually less than 10 per cent in a synthetic medium prepared from c.p. ingredients." This iron effect is negligible in comparison with the 20- to 80-fold effect commonly obtained with coenzyme R preparations. Likewise, our work (3) showed that "reducing substances, such as cysteine, thioglycollic acid, and glutathione, do not in any degree act as substitutes for coenzyme R." In studies of nitrogen sources, ammonium chloride, ammonium nitrate, and ammonium sulfate usually gave poorer growths than potassium nitrate, and hence the latter was commonly used. As a nitrogen source, asparagin is as good as, and sometimes slightly better than, potassium nitrate, but it usually contains a trace of growth factor present as an impurity.

In view of the statements of Thorne and Walker (11), the present further investigations were made of the effect of altering the medium in the various ways mentioned by them. It was especially desired to determine whether such changes would make coenzyme R unessential to the growth of the strains of rhizobia that ordinarily appear to require its addition to the medium.

## METHODS

The basal medium used had the following composition: $K_2HPO_4$, 0.8 gm.; $KH_2PO_4$, 0.2 gm.; NaCl, 0.2 gm.; $MgSO_4 \cdot 7H_2O$, 0.2 gm.; $CaSO_4 \cdot 2H_2O$, 0.1 gm.; and $H_2O$, dist., 1,000 cc. The two phosphate salts were dissolved first, and solutions of the other salts were then added. The medium was allowed to stand until the resulting precipitate had settled, and then the clear solution was siphoned off for use as needed. Iron was then added at the rate of 5 p.p.m., either as ferric chloride (tables 1–3) or as ferric sulfate (tables 4 and 5), and the precipitate that formed was allowed to remain. Sucrose, c.p., previously tested and known to be nearly free from coenzyme R, was usually supplied at the rate of 3 gm. per liter. This low concentration, which is adequate for heavy growths of rhizobia, reduces the quantity of growth factor added as impurity. Nitrogen was added, at the rate of 2.5 mgm. per 25 cc. of medium, in the form of potassium nitrate, ammonium chloride, or asparagin (recrystallized). Since this medium is saturated with respect to certain salts, 10 per cent additional water was added before autoclaving in order that it would remain clear. A little brom thymol blue was added in some cases where it was desired to observe the changes in pH during growth. Prior to inoculation the pH was approximately 7.2. All experiments were carried out in 250-cc. cotton-stoppered

Erlenmeyer flasks, containing 25 cc. of medium, and at a temperature of 28°C.

The coenzyme R preparation used in all experiments except that reported in table 5, was a concentrated acetone extract of an *Azotobacter vinelandii* culture medium (7).

The cultures of rhizobia used were obtained from I. L. Baldwin, University of Wisconsin; D. W. Thorne, Iowa State College; and A. I. Virtanen, Helsinki, Finland. The species, strain numbers, and sources are given in connection with each of the tables. Growth measurements are reported in terms of numbers of bacteria as determined by direct microscopic counts, using a Levy-Hausser bacterial counting chamber having a depth of 0.02 mm.

## NITROGEN SOURCES

In table 1 are reported the results of growth experiments with three species of rhizobia, grown with ammonium chloride, potassium nitrate, and asparagin

TABLE 1

*Effect of coenzyme R on growth of rhizobia with different nitrogen sources*

(Millions of bacteria per cc. on 5th day)

| TREATMENT | RH. TRIFOLII 205* | RH. MELILOTI 131* | RH. LEGUMINOSARUM 302* |
|---|---|---|---|
| $NH_4Cl$ | 2.0 | 9.6 | 6.8 |
| $NH_4Cl$ + 1.3 p.p.m. co. R | 680.0 | 760.0 | 460.0 |
| $KNO_3$ | 9.2 | 9.8 | ..... |
| $KNO_3$ + 1.3 p.p.m. co. R | 1180.0 | 880.0 | ..... |
| Asparagin | 2.0 | 16.4 | ..... |
| Asparagin + 1.3 p.p.m. co. R | 1040.0 | 920.0 | ..... |

* Cultures obtained from University of Wisconsin.

added to the basal medium in the presence and in the absence of the growth accessory substance. Each flask, containing 25 cc. of culture medium, was inoculated with 2 drops (900,000 organisms) of 3-day cultures grown on a medium containing very small amounts of coenzyme R.

The data of table 1 show that in the absence of coenzyme R scarcely any growth was obtained with the three cultures of rhizobia used. In the presence of 1.3 p.p.m. of the growth accessory substance, growth increases varying from 56- to 520-fold were obtained, irrespective of whether ammonium chloride, asparagin, or potassium nitrate was used as the nitrogen source. In the presence of coenzyme R, growth with ammonium chloride was definitely poorer than with either asparagin or potassium nitrate, because of the lower pH that developed with the chloride. This experiment shows, therefore, that the strains of rhizobia used were unable to make appreciable growths within 5 days on a medium containing adequate iron and the reduced forms of nitrogen suggested by Thorne and Walker, but deficient in coenzyme R. The data in

tables 2, 3, and 4, discussed in some detail below, show similar results. These data are also in agreement with those of Clark (6), who used ammonium chloride as a nitrogen source in his experiments.

### EFFECT OF REDUCING AGENTS

The effects of additions of the reducing agents, thioglycollic acid and cysteine, on the growth of *Rh. trifolii* and *Rh. meliloti* in ammonium chloride and potassium nitrate media, and in the presence and absence of coenzyme R, are shown in table 2. The medium and the experimental procedure used were the same as those for the experiment reported in table 1. The thioglycollic acid was pipetted aseptically from the original bottle, neutralized with sterile KOH solution, and added to the medium after sterilization. The cysteine was sterilized separately in the autoclave before addition to the various flasks of sterile media. Each flask was inoculated with 2 drops (about 900,000 organ-

TABLE 2

*Effect of reducing agents on growth of rhizobia in presence and absence of coenzyme R*

(Millions of bacteria per cc. in 4 days)

| TREATMENT | RH. TRIFOLII 205* | | | | RH. MELILOTI 131* | | | |
|---|---|---|---|---|---|---|---|---|
| | $NH_4Cl$ | | $KNO_3$ | | $NH_4Cl$ | | $KNO_3$ | |
| | No co. R | Co. R | No co. R | Co. R | No co. R | Co. R | No co. R | Co. R |
| Control | 1.4 | 780.0 | 9.6 | 680.0 | 8.0 | 540.0 | 9.8 | 660.0 |
| Thioglycollic acid 0.01 per cent | 1.4 | 720.0 | 7.0 | 680.0 | 7.6 | 600.0 | 10.2 | 680.0 |
| Thioglycollic acid 0.002 per cent | 1.4 | 780.0 | 38.0 | 700.0 | ... | 620.0 | 12.8 | 700.0 |
| Cysteine HCl 0.01 per cent | 1.2 | 320.0 | 7.8 | 540.0 | 4.8 | 620.0 | 10.0 | 700.0 |
| Cysteine HCl 0.002 per cent | 1.2 | 780.0 | 6.2 | 700.0 | 6.2 | 640.0 | 11.0 | 840.0 |
| Cysteine HCl 0.0004 per cent | 1.4 | 800.0 | 6.8 | 660.0 | 9.6 | 620.0 | 11.6 | 700.0 |

* Cultures obtained from University of Wisconsin.

isms) of a 5-day culture grown on a medium containing very small amounts of growth factor. The inoculations of the media containing ammonium chloride were with organisms grown on ammonium chloride; likewise, organisms grown on $KNO_3$ were used to inoculate media containing $KNO_3$.

Neither of the reducing agents, when added to a medium containing adequate iron and either ammonium chloride or potassium nitrate, acted as a substitute for coenzyme R. The effects of both thioglycollic acid and cysteine, when added at nontoxic concentrations, were slight, both in the presence and in the absence of the growth factor, and with the two cultures of rhizobia. It is well to point out that in this experiment the numbers of organisms added in the inocula were fairly large, and hence the effect of reducing agents on initiation of growth with exceptionally small inocula, stressed by Allyn and Baldwin (4, 5), was not an important factor.

Further data on the effect of thioglycollic acid on the growth of 12 cultures

of rhizobia on asparagin and potassium nitrate, are given in table 3. The methods used were, for the most part, the same as those in the two preceding experiments. A little brom thymol blue to serve as a pH indicator was added. The quantity of inoculum used was much smaller, consisting of 1 loopful of a 2-day culture grown on a medium containing very little growth factor. Scarcely any growth was visible macroscopically in these 2-day cultures.

The striking effect of coenzyme R on the growth of the various species and strains of rhizobia both with asparagin and with potassium nitrate is shown in table 3. The inability of thioglycollic acid to act as a substitute for coenzyme R in the presence of abundant iron is also shown very clearly. By using a small

TABLE 3

*Response of various strains of rhizobia to coenzyme R in presence and absence of 0.002 per cent thioglycollic acid*

(Millions of bacteria per cc. in 5 days)

| ORGANISMS* | $KNO_3$ | | | | ASPARAGIN | | | |
|---|---|---|---|---|---|---|---|---|
| | No co. R | | Co. R 1.3 p.p.m. | | No co. R | | Co. R 1.3 p.p.m. | |
| | No thio. | Thio. | No thio. | Thio. | No thio. | Thio. | No thio. | Thio. |
| *Rh. trifolii* 202 | 2.0 | 2.0 | 160.0 | 200.0 | 2.0 | 2.0 | 760.0 | 860.0 |
| " " 205 | 7.0 | 7.4 | 660.0 | 780.0 | 2.0 | 1.8 | 640.0 | 640.0 |
| " " 209 | 0.4 | 0.4 | 640.0 | 700.0 | 0.4 | 0.4 | 640.0 | 440.0 |
| " " VI | 1.4 | 1.4 | 420.0 | 440.0 | 1.0 | 1.0 | 440.0 | 400.0 |
| *Rh. leguminosarum* 302 | 4.0 | 3.6 | 640.0 | 600.0 | 4.0 | 4.0 | 540.0 | 600.0 |
| " " 310 | 1.0 | 1.0 | 660.0 | 620.0 | 1.0 | 1.0 | 620.0 | 660.0 |
| " " 317 | 1.0 | 1.0 | 600.0 | 620.0 | 1.0 | 1.0 | 380.0 | 480.0 |
| " " XX | 1.0 | 1.0 | 300.0 | 300.0 | 1.0 | 1.0 | 640.0 | 680.0 |
| *Rh. phaseoli* 402 | 1.0 | 1.0 | 460.0 | 400.0 | 1.0 | 1.0 | 1.0† | 340.0 |
| *Rh. meliloti* 101 | 0.4 | 0.4 | 80.0† | 760.0 | 0.4 | 0.4 | 400.0 | 460.0 |
| " " 131 | 10.0 | 9.6 | 820.0 | 880.0 | 5.0 | 6.0 | 900.0 | 880.0 |
| " " 113 | 8.0 | 6.0 | 600.0 | 620.0 | 10.0 | 4.0 | 620.0 | 620.0 |

* *Rh. trifolii* VI and *Rh. leguminosarum* XX cultures obtained from A. I. Virtanen, Helsinki, Finland; all other cultures obtained from University of Wisconsin.

† On the 7th day the numbers of bacteria in these flasks were about 60 per cent as large as those in the corresponding flasks to which thioglycollic acid had been added.

quantity of inoculum and a very pure sugar the essentialness of coenzyme R is made more evident.

Although thioglycollic acid did not act as a substitute for coenzyme R it did increase the growth of 2 of the 12 strains of organisms used. With one of these strains the favorable effect occurred in $KNO_3$ but not in the asparagin medium, whereas with the other organism the reverse was true. This favorable effect of thioglycollic acid may have been due to its effect on growth initiation where the inoculum is small. The numbers of organisms added in the inoculum varied for the 12 strains from less than 1,000 to about 5,000 per cubic centimeter of the final culture medium.

SPECIES AND STRAINS OF RHIZOBIUM

The results given in tables 1–3 of tests with 4 species and a total of 12 strains of *Rhizobium*, which ordinarily make good growths on yeast extract media, show a close agreement as far as need for coenzyme R is concerned. Considering, however, that some of the results reported by Thorne and Walker (11), especially those in table 1 of their paper, appear to be in distinct disagreement

TABLE 4

*Growth of rhizobia on asparagin and potassium nitrate in presence and absence of coenzyme R*

(Millions of bacteria* per cc.)

| NITROGEN SOURCE AND ORGANISMS† | TRANSFER NO. 1 | | | | TRANSFER NO. 2 | | | | TRANSFER NO. 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No co. R | | Co. R | | No co. R | | Co. R | | No co. R | | Co. R | |
| | 4th day | 9th day | 4th day | 9th day | 5th day | 9th day | 5th day | 9th day | 5th day | 9th day | 5th day | 9th day |
| Asparagin | | | | | | | | | | | | |
| *Rh. meliloti* 101 | 52 | 80 | 1180 | 2000 | 36 | 40 | 1460 | 2000 | 16 | 20 | 1280 | 2000 |
| " " 110 | 50 | 80 | 1040 | 2000 | 52 | 60 | 1120 | 2000 | 32 | 20 | 1060 | 2000 |
| " " 123 | 48 | 80 | 240 | 2000 | 52 | 60 | 220 | 1500 | 14 | 20 | 280 | 1600 |
| " " 132 | 12 | 20 | 132 | 1200 | 14 | 20 | 30 | 240 | 22 | 20 | 162 | 1400 |
| *Rh. trifolii* 205 | 20 | 14 | 1760 | 2000 | 14 | 20 | 900 | 1800 | 8 | 0 | 900 | 2000 |
| " " 206 | 14 | 14 | 1160 | 2000 | 30 | 20 | 620 | 2000 | 20 | 20 | 740 | 2000 |
| " " 208‡ | 14 | 0 | 920 | 2000 | 12 | 20 | 400 | 2000 | 18 | 20 | 800 | 2000 |
| " " 205 | 12 | 14 | 1860 | 2000 | 34 | 40 | 1640 | 2000 | 16 | 0 | 840 | 2000 |
| Potassium nitrate | | | | | | | | | | | | |
| *Rh. meliloti* 101 | 56 | 80 | 1160 | 2000 | 12 | 20 | 700 | 2000 | 12 | 20 | 120 | 1500 |
| " " 110 | 54 | 140 | 1300 | 2000 | 28 | 60 | 1160 | 2000 | 20 | 20 | 500 | 2000 |
| " " 123 | 42 | 60 | 1340 | 2000 | 6 | 60 | 1180 | 2000 | 6 | 20 | 640 | 2000 |
| " " 132 | 32 | 60 | 380 | 2000 | 22 | 40 | 170 | 1600 | 12 | 20 | 260 | 1800 |
| *Rh. trifolii* 205 | 16 | 20 | 1180 | 2000 | 20 | 40 | 780 | 2000 | 16 | 20 | 1220 | 2000 |
| " " 206 | 22 | 20 | 1300 | 2000 | 40 | 60 | 920 | 2000 | 22 | 20 | 2000 | 2000 |
| " " 208‡ | 26 | 120 | 720 | 2000 | 18 | 60 | 700 | 2000 | 18 | 40 | 820 | 2000 |
| " " 205 | 30 | 40 | 940 | 2000 | 14 | 40 | 1500 | 2000 | 22 | 20 | 1120 | 2000 |

* The figures given for the 4th and 5th day growths are microscopic counts, whereas the figures for the 9th day are estimates. In the case of the highest figures given, 2000 millions per cc., the actual numbers present are, in many instances, probably considerably higher than this figure.

† *Rh. trifolii* 205 culture obtained from University of Wisconsin; all other cultures obtained from Iowa State College.

‡ All results reported with this organism were obtained at a later date than in the case of the other organisms.

with those reported here in tables 1–3, it seemed desirable to determine whether the difference was due to the bacterial strains used. Using cultures which D. W. Thorne very kindly supplied, we carried out an experiment in which their experimental conditions (11, table 1) were duplicated fairly closely. Our usual medium, described above, was used, except that, in order to reduce the quantity of growth factor added as an impurity, only 0.2 per cent c.p. sucrose was added.

Three successive transfers were made, using 1 cc. of inoculum per 25 cc. of medium, according to their method. The first transfer was made from cultures grown on commercial sucrose medium which contained some accessory substance. In the subsequent successive transfers all inoculations were made from the corresponding flasks of the preceding series to which no growth factor had been added.

The results with seven bacterial strains obtained from Thorne, reported in table 4, are in agreement with the data in tables 1–3. These organisms made only a very slight growth on a medium containing either asparagin or potassium nitrate and adequate iron unless coenzyme R was added. This was true even though 1 cc. of inoculum was used. The growths over a 5-day period were, on the average, not greatly different with asparagin and potassium nitrate; some strains preferred one nitrogen source, and some strains preferred the other. The different results obtained by Thorne and Walker are therefore not due to strain variation.

In these and other studies not reported here it has been observed frequently that most strains of *Rh. meliloti* make larger growths on relatively small amounts of growth substance than do strains of *Rh. trifolii*. In control flasks where clover bacteria commonly show no macroscopic growth (less than 20 millions per cubic centimeter) the alfalfa organisms may show a definitely positive growth (40–80 millions per cubic centimeter). The reason for this difference has not been determined.

### EFFECT OF VARYING CONCENTRATIONS OF COENZYME R ON GROWTH

Typical results showing the effect of different concentrations of coenzyme R on the growth of three cultures of rhizobia are given in table 5. Each flask was inoculated in duplicate. In experiment 1 two drops of inoculating culture were added to each flask, giving an initial population of approximately 600,000 organisms per cubic centimeter; in experiment 2 the initial population was about 300,000 organisms per cubic centimeter. In both experiments the media contained potassium nitrate and 0.2 per cent of a sucrose known to be fairly low in growth substance. The sample of coenzyme R used, which had been prepared from molasses, was considerably less concentrated than extracts prepared most recently from Azotobacter cultures.

Table 5 shows that, over the concentration range tested, the number of organisms was roughly proportional to the concentration of growth substance added. At the highest concentration of growth factor, there were usually fewer organisms per unit of coenzyme R present, as was to be expected. From the data of experiment 2 it was calculated that the control flasks actually contained coenzyme R equivalent to that in about 0.05 p.p.m. of the coenzyme R preparation added. This was, of course, added in the inoculum and in the sugar.

It appears from these and other results that a definite minimum quantity of growth substance is needed for the formation of each bacterial cell. As was

pointed out previously (2, 3, 7), respiration studies show that additions of coenzyme R at concentrations equivalent to the maximum used in table 5 commonly produce a two- to four-fold increase in respiration during the first few hours and before an increase in numbers occurs. Coenzyme R, therefore, apparently exerts its effect on growth through its initial effect on respiration.

Incidentally, it is desired to point out that the $Q_{O_2}$ (cu. mm. $O_2$ consumed per hour per mgm. dry weight) of rhizobia is much lower than that for many other bacterial species. Unfortunately, in a previous publication (3) it was stated that the $Q_{O_2}$ may reach values as high as 1,000; this figure should have been given as 50. In most experiments it is less than 30.

TABLE 5

*Effect of varying concentrations of coenzyme R on growth of rhizobia*

(Millions of bacteria per cc.)

| QUANTITY OF COENZYME R ADDED | EXPERIMENT 1 | | | | EXPERIMENT 2 | |
|---|---|---|---|---|---|---|
| | *Rh. trifolii* 205* | | *Rh. meliloti* 131* | | *Rh. trifolii* 209* | |
| | 3 days | 7 days | 3 days | 7 days | 4 days | 7 days |
| *p.p.m.* | | | | | | |
| Control | 22 | 48 | 32 | 52 | 10 | 23 |
| 0.1 | 24 | 52 | 30 | 70 | .... | .... |
| 0.2 | 118 | 132 | 66 | 160 | 62 | 93 |
| 0.5 | 164 | 212 | 92 | 300 | 84 | 214 |
| 1.0 | 268 | 720 | 124 | 800 | 181 | 520 |
| 2.0 | ... | .... | ... | ... | 320 | 680 |
| 5.0 | 840 | 1280 | 356 | 820 | 1020 | 1550 |

* Cultures obtained from University of Wisconsin.

## DISCUSSION

The data reported, together with those from numerous other similar experiments not reported, confirm our previous findings that many, but not all, strains of rhizobia require coenzyme R in order to make good growths. We have not attempted to determine whether these organisms can be kept alive and growing slowly for a large number of successive transfers on media containing no accessory growth substance. It would, in fact, be difficult to perform this experiment because of the difficulty in eliminating all traces of the growth factor from the medium, and because the inoculum itself contains the substance. In our experiments we have been interested only in the conditions essential for obtaining *good* growths (500 millions or more bacteria per cubic centimeters in 4 or 5 days).

These experiments also show that iron does not act as a substitute for coenzyme R, and thus, insofar as they are comparable, confirm the conclusions of our previous (2) iron studies. Rhizobia, in contrast to Azotobacter, require so little iron that, in many instances, the iron impurities in the chemicals used are adequate for good growths.

The inability of reducing substances, such as thioglycollic acid and cysteine, to act as substitutes for the growth substance is again shown by the data presented here. Although it is quite possible that coenzyme R acts through the oxidation-reduction system inside the cell, we have not been able to obtain direct evidence for this view. Not only do reducing agents added to the media fail to act as substitutes for coenzyme R, but direct potentiometric measurements show that the addition to the media of our more concentrated preparations at concentrations adequate for maximum growth has essentially no effect on the $E_h$ values of the media.[2]

The conclusion of Thorne and Walker (11) that "no evidence was found which indicates that the root nodule bacteria require any complex, unidentified substances for their growth" is, therefore, contrary to both our earlier and our present experience. Under the experimental conditions, 19 strains of rhizobia, including 7 supplied by Thorne, all of which are capable of making good growth on laboratory media, failed to make *good* growths unless coenzyme R was added. We do not wish to imply, however, that all rhizobia respond to additions of this growth factor. We emphasized previously that the cowpea and soybean bacteria, as well as some of the others that usually grow poorly on laboratory media, ordinarily make little response to additions of coenzyme R. Furthermore, our more recent studies show that an occasional strain of rhizobia of species other than *Rh. trifolii*, *Rh. leguminosarum*, *Rh. meliloti*, and *Rh. phaseoli*, can grow readily on laboratory media to which no coenzyme R has been added. Of 27 strains of the four species mentioned, which we have studied at various times, only 1, however, has been found to make a good growth without additions of the growth substance, and even this strain shows some response to the material. This one strain slowly synthesizes coenzyme R. Studies along this line will be reported shortly. Since strain variation among bacteria is the rule, variations with respect to need for the growth substance are not surprising.

A close study of the paper by Thorne and Walker indicates that the differences between their results and ours lie more in the interpretation of the data than in the data themselves. Although they report that good growths were repeatedly obtained, and for a large number of transfers, in a purified medium containing ammonium chloride or asparagin as a nitrogen source, they also state that "the accessory substances reported by Allison and Hoover are able to induce large increases in the growth and respiration of Rhizobium in media composed of highly purified materials. This stimulative effect has been noted in media with $NH_4Cl$ or asparagin, as well as $KNO_3$ as the source of nitrogen." Thorne and Walker therefore presented the view that coenzyme R is a non-essential, rather than an essential, growth substance. This interpretation involves the assumption that the growth they observed was not due to small quantities of growth substance, added unintentionally. On the other hand, we are strongly of the opinion that the scanty growths we obtain in the ab-

[2] Allison, F. E., and Minor, F. W. Unpublished results.

sence of intentionally added growth substance are due entirely to traces in the sugar and in the inocula used. If very small growths are to be obtained in such control flasks the coenzyme R in the medium must be reduced to the minimum by careful purification of all chemicals used and by inoculating with a relatively small number of organisms that have been grown on a medium low in growth factor.

A large number of empirical tests of various chemical compounds and growth factors essential for other organisms have not shown any of them to be coenzyme R. The actual chemical constitution of the substance has not been determined, but, as stressed before, there is nothing to indicate that it is a heavy metal, as suggested by Steinberg (9, p. 447). It is almost certainly an organic compound, not only because of its properties, but also because it is synthesized by various organisms. For instance, Azotobacter grows vigorously and synthesizes coenzyme R in a medium in which rhizobia fail to grow. If a little of this Azotobacter culture, or an alcohol extract of it, is added to some of the original medium, rhizobia will then grow rapidly in it.

## SUMMARY

A total of 19 typical strains of *Rh. trifolii*, *Rh. meliloti*, *Rh. leguminosarum*, and *Rh. phaseoli* were found to require the addition of coenzyme R to the medium in order to make an appreciable growth. The experiments show that: (*a*) iron did not act as a substitute for the essential growth substance, (*b*) reducing substances, such as thioglycollic acid and cysteine, had very little effect on the growth of rhizobia either in the presence or in the absence of coenzyme R, (*c*) the need for accessory growth substance was equally evident whether the nitrogen source was sodium nitrate, ammonium chloride, or asparagin, and (*d*) the total growth of rhizobia over a limited range of concentrations (25- to 50-fold) of coenzyme R was very roughly proportional to the quantity of growth substance added, except in some instances at the higher concentrations.

These new data are in agreement with our previous results and in disagreement with the more recent report of Thorne and Walker that rhizobia do not require any complex, unidentified substances for their growth. Although an occasional strain of rhizobia can grow rapidly without the addition of coenzyme R, this fact has little bearing on the results reported either by Thorne and Walker or by us, since some of the same strains of bacteria were used in the two investigations.

The chemical nature of coenzyme R has not been determined, but it is unquestionably an organic compound. It is synthesized by many organisms and produces a marked increase in the respiration and growth of rhizobia.

### *Addendum*

After this paper had been prepared for publication, the report of the investigations of R. Nilsson, G. Bjälfve, and D. Burström [Über Zuwachsfaktoren bei Bact. radicicola. *Annal. Landw. Hochsch. Schwedens* 5: 291–322 (1938)] and those of G. Bjälfve and R. Nilsson [Stroh

als Nährboden für Bact. radicicola und andere Mikroorganismen. Ibid. 71–88] appeared in print. Both papers show the inability of *Rh. trifolii* to grow in the absence of an essential growth substance. Nilsson, Bjälfve, and Burström obtained no growth on a synthetic medium with $KNO_3$, $NH_4Cl$, or asparagin as the nitrogen source, but when yeast extract was added, normal growth occurred. Likewise, the addition of glyceric aldehyde, cysteine hydrochloride, or glutathione did not enable the bacteria to grow in the absence of essential growth substance. They conclude from their experiments, carried out in part for the purpose of checking the results of Thorne and Walker as well as those reported by us, that "Nur nach Zugabe von gewissen Extrakten aus nativem Material erfolgt ein Wachstum auf den synthetischen Medien."

*Note added to galley proof.* More recently P. M. West and P. W. Wilson [Synthesis of growth factors for *Rhizobium trifolii*. *Nature* 142: 397–398 (1938) and Growth-factor requirements of *Rhizobium trifolii*. *Jour. Bact.* 36: 306–307 (1938)] reported the existence of a growth-connected factor for rhizobia which, since it is thermolabile, is obviously not indentical with coenzyme R.

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## BOOK REVIEWS

*Productive Farm Crops.* By E. G. MONTGOMERY. J. W. Lippincott Company, New York, 1938. Pp. viii + 521, illus. 222.

The present volume is the fifth edition of a well-known book. It is more complete than the earlier editions and has been markedly improved from the standpoint of craftmanship.

At this particular time, producers of farm crops need more help and guidance than they ever did before in planning the production of staple agricultural commodities. The author is well aware of this situation. In the preface to the fifth edition, he says:

> In the preparation of this book, the author has endeavored to develop the fundamental principles of crop production, as demonstrated by practical experience. In general the principles referred to are supported by experimental evidence. No exhaustive analysis of experimental evidence is attempted, but only sufficient to clearly prove the principles. Involved and debatable problems are generally avoided, as there is sufficient standard and accepted work for the scope of this book.
>
> The text is intended for the use of students having some practical knowledge of crop production. It is hoped to meet the needs of students taking a general agricultural course. Being of a practical nature, the book will also be found a handy book for farmers desiring a reference book covering all agricultural crops.

The book contains 45 chapters, which are entitled respectively: Classification, Origin and Distribution of Field Crops; How Plants Grow; The Production of Seeds; Comparative Study of Cereals; Cropping Systems; Corn; Climate and Soil Required for Corn; Corn Culture; Preparation of Land for Corn; Tillage for Corn; Harvesting and Utilizing Corn; Corn Insects and Diseases; Pop-Corn and Sweet Corn; Corn Judging; Wheat; Origin and Description of Wheat Types; Wheat Culture; Harvesting, Marketing, and Utilizing Wheat; Diseases and Insect Enemies; Oats; Culture of Oats; Harvesting and Utilizing the Oat Crop; Barley; Rye; Buckwheat; Cotton; Cotton Culture; Flax; Sorghums; Irish Potatoes; Culture of Irish Potatoes; Sweet Potatoes; Classification and Distribution of Forage Crops; Characteristics of Economic Grasses and Legumes; Grass Mixtures—Seeds and Seeding; Care of Grass; The Principal Cultivated Grasses; The Secondary Grasses; Millets; Legumes; Alfalfa; The Clovers; Cow Peas, Soy Beans, Field Peas, Vetches, Peanuts; Root Crops; and Tobacco Production. There are also three appendixes and an index. The appendixes are designated, respectively: Legal Weights per Bushel of Seeds; Market Grades of Hay and Straw; and Grades of Grain.

The student, as well as the progressive farmer, will find much useful information in this book. The information will help him to orient himself as to domestic production, production in foreign countries, and export and import

markets. He will also be able to utilize this information in planning his livestock enterprises. Moreover, the producers in different sections of the United States will gain a better perspective of the important producing areas and the distribution of crop production in the United States.

*The Chemical Analysis of Foods and Food Products.* By MORRIS B. JACOBS. D. Van Nostrand Company, Inc., New York, 1938. Pp. xx + 537, figs. 56, tables 65.

The value of foods is no longer to be measured in quantitative terms alone. Nutrition studies of many sorts have taught us that the products used in the feeding of farm animals and of humans vary widely in their composition. They vary as widely in their ability to provide for maintenance and growth. For one thing, well-informed persons attach proper importance to the content of phosphorus and calcium in foods. The so-called *minor* ingredients of plant ash are being evaluated intelligently. The place of vitamins, hormones, and of other plant constituents in nutrition is now more clearly understood. For this and other reasons, *The Chemical Analysis of Foods and Food Products* will be found useful to the laboratory technician, to the chemist, and to the dietitian.

The author was clear in his own mind as to the scope of his undertaking. He notes in his preface:

> This book was written with a number of objectives. First and foremost was the desire of the author to give systematic coverage to the salient facts of the chemical analysis of foods and food products and to include certain of the newer aspects of food analysis such as the chemical assay of vitamins, the detection of improper pasteurization of milk, the homogenization of milk, the detection of gums and methods for the detection of newer types of sophistication of foods. Many important analytical procedures have been entirely neglected, not only in literature, but even by so eminent a society as the Association of Official Agricultural Chemists whose latest edition of methods, 1935–36 contains no word on the detection of improper pasteurization of milk, nor any chemical methods for the vitamins although Tillman's method for vitamin C has been recognized as adequate since 1928.

The book is made up of 17 chapters, entitled respectively: General Methods; Physical Chemical Methods; Coloring Matter in Foods; Preservatives in Foods; Metals in Foods; Milk and Cream; Milk Products; Oils and Fats; Sugar Foods and Carbohydrates; Gums, Cereals, Starch and Other Polysaccharides; Jams, Jellies, Fruits; Spices, Flavors and Condiments; Non-alcoholic Beverages and Allied Products; Alcoholic Beverages; Meat, Meat Products, Fish and Eggs; Vitamins; and Inorganic Determinations. Appendix tables cover 27 pages, and there are adequate subject and author indexes.

Altogether, the volume should prove to be a distinct aid to many persons, not least among them the technicians who are searching for new industrial uses of agricultural products.

*Physical Chemistry.* By J. N. BRÖNSTED. The Chemical Publishing Co. of New York, Inc., 1938. Pp. xv + 394, tables 30, figs. 73. Price $5.00.

In his foreword to the book, Prof. F. G. Donnan, of the University of London, says:

> An outstanding feature of this work lies in its systematic application of the thermodynamical methods of Willard Gibbs. The clarity, security and elegance of treatment thereby obtained are apparent on almost every page. For this achievement, Professor Brönsted is to be heartily congratulated.

By way of further acquainting the reader with the nature of this book, the following may be quoted from the preface to the English edition.

> The present book is a translation of the author's "Laerebog i fysisk Kemi," which was published in 1936, and forms the basis for instruction in physical chemistry at Copenhagen University and the Danish Technical College.
>
> In this text-book special emphasis is laid on the thermodynamic foundation of physico-chemical laws. The treatment employed is based upon the "thermodynamic functions" of Gibbs, since in the author's opinion this is the easiest way of attaining the combination of simplicity and rigour which should be the aim of a theoretical text-book. It is often supposed that the conception of thermodynamic functions is a difficult one, and that their use demands special powers of abstract thought. It is the author's view, however, that this is not in general the case, while even if such difficulties should occur they will be amply compensated by the uniformity of treatment and certainty of operation which characterise the methods of Gibbs.

There are altogether 11 chapters in this volume. The titles of these chapters follow: The Laws of Thermodynamics; States of Aggregation; Molecular Theory; Mixtures; The Theory of Dilute Solutions; Homogeneous Equilibria; Electrolytes; Reaction Kinetics; Electrochemistry; Affinity; and Surface and Colloid Chemistry.

It is to be regretted that a book of such fine quality is not provided with a satisfactory subject index. However, this should not lessen the merits of the author's contribution to a rapidly expanding field of chemistry.

*Agricultural Analysis*. By C. HAROLD WRIGHT. Thomas Murby & Co., London, 1938. Pp. ix + 343, figs. 8. Price 16s net.

The author is already known for his *Soil Analysis*, a handbook of physical and chemical methods. The publication of the revised edition of this work is now pending. In his *Agricultural Analysis* the author deals with methods exclusive of those used for the examination of soils.

As a laboratory manual, the present work is intended to serve students, teachers, and laboratory technicians. To quote the author:

> This book is a laboratory manual giving the details of the methods of analysis of fertilizers, feeding stuffs, milk, milk products, insecticides and fungicides with reference to the sources of information. It also contains the preparation of the indicators and standard solutions used in the methods described and the data required for calculating the results. It is intended for agricultural analysts with limited library facilities, but it is hoped that it will also be of use to research workers and advanced students.

The major topics dealt with by the author are entitled, respectively: Introduction; Preparation of the Sample; Nitrogenous Fertilizers; Phosphatic

Fertilizers; Phosphate Rock; Potassic Fertilizers; Lime and Limestone; Organic Constituents of Feeding Stuffs; Mineral Constituents of Feeding Stuffs; Milk; Milk Products; Insecticides and Fungicides; and Solutions for Volumetric Analysis. There are also three appendixes (entitled: International Atomic Weights; Gravimetric Factors and their Logarithms; and Volumetric Factors and their Logarithms), and an author and subject index.

Aside from the general and popular information contained in this book, the reader will find direct and helpful reference to various official methods employed in the analysis of agricultural products.

*Guide to Eastern Ferns.* By EDGAR T. WHERRY. The Science Press Printing Company, Lancaster, Pa., 1937. Pp. iv + 220, illus. 102.

This is a most interesting little volume. The horticulturist and the professional and amateur gardener will welcome it. The descriptions of the different ferns in the eastern region will serve as a direct aid to the teacher and the student alike. In the words of the author:

> This guide has been prepared to fill a need for an aid in the identification of the ferns and fern-allies of the region from Pennsylvania and New Jersey to Virginia, of convenient size for field use, and, though non-technical, free from errors and misidentifications such as occur in several current fern books. The data as to each species are presented under five headings: History; Features, especially those not brought out by the drawings; Habitat, ascertained by extensive field work; Range, as known to date; Remarks, comprising methods of distinguishing similar species, and corrections of certain errors often made in amateur writings on these plants, which, once published, get copied by one uninformed writer after another indefinitely.

Aside from the introduction, the book contains a glossary of technical terms; a classification; illustrations and descriptions of species; a discussion of fern cultivation; and an index to genera.

This book should find a place on the reference shelf of the gardener and botanist.

*Animal Nutrition.* By LEONARD A. MAYNARD. McGraw-Hill Book Company, Inc., New York and London, 1937. Pp. xiv + 483, tables 33, figs. 36. Price $4.00.

The conversion of plant products into animal products represents one of our major economic enterprises. On the foundation built by the soil technologist and the agronomist, the geneticist has worked successfully toward the development of better and more profitable strains of livestock. But, even with the best foundation of farm animals, economic returns are not possible except as rational management and effective nutrition methods are employed.

The present work is a valuable contribution on the subject of animal feeding. In the author's own words:

> Nutrition is a chemical process and its principles must be presented in chemical terms. It is assumed that the student has an elementary knowledge of organic chemistry and of physiology. The early chapters of this book provide a review and extension of this knowledge as

related to those substances and processes with which nutrition deals. These discussions are limited to the essentials of the language in which the principles of nutrition must be presented.

In the discussion of growth, reproduction, lactation, and other body functions particular attention is given to the nutritive requirements of the various species of farm animals. But the major purpose is to teach how the facts of nutrition are being learned experimentally and how they find application in practice. A consideration of the detailed feeding practices which differ for the various species lies outside the scope of this book; but the discussions here included should provide a background for a better understanding of these practices as presented in the production courses for the various species.

The book contains a preface and 16 chapters. These are entitled: The Expanding Field of Nutrition—An Introduction; The Animal Body and Its Food; Some Physical Bases of Life Processes; The Carbohydrates and Their Metabolism; The Lipids and Their Metabolism; The Proteins and Their Metabolism; The Inorganic Elements and Their Metabolism; The Vitamins; Feeding Experiments. The Determination of Digestibility; Nutritional Balances; Measures of Total Nutritive Energy; The Fasting Catabolism. Maintenance; Growth; Reproduction; Lactation; and Work Production. Both the author index and the subject index make the book more useful for reference purposes.

The teacher and the student will derive much satisfaction from this work, not alone because of the satisfactory arrangement of the material presented, but also because of the numerous references cited and the lines of thought which the reading of the book will develop.

*The Soybean Industry.* By A. A. HORVATH. The Chemical Publishing Co. of New York, Inc., 1938. Pp. vi + 221. Price $4.00.

The two Americas owe much to the Old World for the plant material that it has contributed to our crop resources. The soybean is one of the remarkable contributions of Asia to the economic resources of North America. It came to the shores of this continent after the middle of the nineteenth century. Its economic possibilities were not appreciated at that time. The first introductions were accepted as new botanical specimens to be grown in our botanic gardens. In the course of time, the soybean became one of our important staple crops. More recently, it was recognized as a source of raw materials for nonagricultural industries. This is precisely the point of view that guided the author in the preparation of *The Soybean Industry*. In the introduction to his book, he says:

One of the most striking agricultural developments in the United States in recent times has been the rapid rise of the soybean. In 1907 there were 50,000 acres; in 1935, nearly 5,500,000. In 1920, seed production was 3,000,000 bushels; in 1935, about 40,000,000. Remarkable progress has been made in the last few years in developing food and industrial uses for the soybean, the oil, and meal. At present about 45 oil mills, including a few cottonseed oil mills, are crushing soybeans; more than 40 concerns are manufacturing soybean food products and soybean flour; and more than 75 factories are turning out various industrial products made from soybeans. Soybean oil has become an important product in many industries. In addition to the use of the meal in livestock feeds, considerable quantities are

utilized in the manufacture of foods and industrial products. As yet, however, we are only beginning to suspect the extent of the potentialities which further scientific research may discover and which commercial development may transform into actualities.

Aside from the introduction, the body of the book is made up of 20 chapters, a bibliography, a list of useful books, and an index. The chapters are designated as follows: Edible Whole Soybean Flour; Pressure Oil Milling; Oil Milling (machinery and procedures); Press Oil; Press Meal; Solvent Extractions; Safety in Solvent Extraction and in Flour Milling; Efficiency of Solvents and Their Effect on Oil Quality; Experimental (Laboratory) Extraction of Phosphatides; Commercial Extraction of Phosphatides; Soybean Oil; Refining of Soybean Oil; Blown, Sulfonated and Hydrogenated Oil; Technical Uses of Soybean Oil, Core Oil and Cutting Fluid; Phosphatides (Lecithins) and Their Uses; Soybean Protein; Industrial Protein; Plastics; Adhesives and Sizing Materials; and Solvent Extraction Meal.

To say the least, this book will help both the agronomist and the technologist to orient themselves in a rapidly expanding field. The oils, fats, and plastics derived from soybeans will become economically more important with the passing years.

*The Science and Practice of Canadian Animal Husbandry.* By J. W. G. MacEwan and A. H. Ewen. Thomas Nelson & Sons Limited, Toronto, Canada, 1936. Pp. xiv + 462, illus. 45.

The authors and publishers of this book are to be commended for a task well done. The paper, the printing, and the illustrations are all of fine quality; but what is more important is the presentation of the subject matter. The vast extent of Canada, its climate, and its soils have already encouraged the establishment and development of one of the great livestock enterprises of the world. There is room for much expansion. The present book may be accepted as one of the means to that end. A part of the foreword, written by James G. Gardener, may well be quoted in this connection.

The live-stock industry of our Dominion takes many forms, depending somewhat on geographic, climatic and soil conditions. Whatever the phase of live-stock production, whether it be ranching or farm production, dairying or meat production, pure bred or commercial production, it calls for the highest type of personal initiative and skill. Breeders are entrusted with the responsibility of controlling the intricate processes of heredity and hence the type and utility of farm animals, while the problems of feeding and nutrition are scarcely less complex and deserving of study. The demand for our live-stock products at home and abroad depends greatly upon the quality we are able to maintain and the skill with which our tasks are completed.

Reference may also be made to the first paragraph in the authors' preface:

Numerous inquiries received from farmers, stock men and students testify to the need for a treatise on Canadian Animal Husbandry. The following chapters represent an effort to meet that need, and in so doing to include under one cover the essential points about the theory and practice of breeding, feeding, management and related problems. It has been

the constant aim of the authors to treat the subject matter in such a manner that the book would serve as a text for students of agriculture and a guide and reference to practical live-stock breeders.

The contents of the book include a foreword, a preface, and 23 chapters grouped under seven parts. These parts are entitled, respectively: The Principles of Breeding; Breeds of Live-Stock in Canada; Principles of Nutrition; Feeds; Feeding and Management of Farm Stock; Marketing of Live-Stock; and Farm Meats. The chapters themselves are designated: Animal Genetics; Reproduction; Fertility-Sterility; Breeding Practices; Breeds of Cattle; Breeds of Sheep; Breeds of Pigs; Breeds of Horses; Physiology of Digestion; Constituents of Feeds; Feeding Standards; The Practice of Feeding; Concentrates; Pastures, Hays, Straws; Roots and Tubers; Silos and Silage; Dairy Cattle; Beef Cattle; Sheep; Pigs; Horses; Marketing of Live-Stock; and Farm Meats. There are also 7 appendixes, a bibliography, and an index.

The book will be found to be a source of useful information for the teacher, the student, and the breeder and feeder of farm animals.

*Soilless Growth of Plants.* By CARLETON ELLIS AND MILLER W. SWANEY. Reinhold Publishing Corporation, New York, 1938. Pp. 155, frontispiece, figs. 58. Price $2.75.

It may be that the recent publicity about so-called *dirtless farming* has given the reading public an exaggerated notion about the production of plants in sand or water culture. None the less, there are two important fields that relate to the subject dealt with by the authors. One is the field of soil science: the other is that of economics.

The following paragraph, quoted from the foreword, will help the reader to understand the purpose of the authors in preparing this book:

In the past few years so great a degree of interest has been aroused in so-called soilless growth that a popular discussion of the subject seems in order. The present text was written after numerous laboratory tests and investigations had been carried out. It is hoped that this volume will prove useful to those who desire to grow plants by the methods described herein.

Reference may also be made to a paragraph from the introduction. This paragraph reads:

Like so many other practices, that of soilless growth continued practically unnoticed by the non-technical person until a very few years ago; and within recent months there has been an enormous surge of popular interest in this art of growing plants. The essential feature of the soilless method is the use of so-called "nutrient solutions," which merely consist of chemical plant food dissolved in water. A number of small water-culture gardens employing these nutrient solutions have been in operation during the past year or so, and a considerable number of greenhouse establishments are at present producing both vegetables and flowers by this method of cultivation. Soilless growth is also known as "hydroponics," aquaculture, water-culture, tray agriculture, or tank farming. When carried on in the proper manner, it enables one to obtain plants of considerably larger size than is ordinarily attained in soil. For instance, tomato vines 23 feet in height have been reported grown by soilless methods.

Aside from the foreword and the introduction, the book contains 8 chapters and an index. The chapters are entitled, respectively: Chemistry of Plant Life; Growing in Mineral Aggregates; Growing in Water; Household Plant Culture; Commercial Aspects; Special Chemicals; Common Detriments; and Nutrient Formulas.

The entire subject is a fascinating one. The average person is fond of plants. He finds joy in watching them grow. He will, no doubt, obtain added inspiration from some of the recent developments in plant production—not least among them those described by the authors.

*Annual Review of Biochemistry*, Vol. VII. JAMES MURRAY LUCK, Editor, AND CARL R. NOLLER, Associated Editor. Annual Reviews, Inc., Stanford University P. O., California, 1938. Pp. ix + 571. Price $5.00.

The present volume is the seventh of the series. It brings up to date an account of scientific findings rich in facts and suggestions. The editors of the book have rendered and are rendering an extremely valuable service. They have been fortunate in the selection of contributors—each working in his special field.

It would be proper to quote a portion of the preface. It is noted there that

> An introduction to the present volume of the Review can refer to very few matters that have not received mention in the earlier volumes. Each year, however, it is a pleasure to recall those phases of our editorial duties that bring us into association with the contributors of the reviews and with some of the readers. The cooperation of our colleagues, year by year, in preparing these reviews has been most cordial and complete, despite the vexatious restrictions and importunities with which we perennially tax their patience. Every investigator in biochemistry, impressed as he must be by the fertility of research and the wealth of literature in this expanding science, cannot but be appreciative of the difficulties that attend the labors of a reviewer—the selection of papers for review, their critical interpretation, and their integration into a coherent chapter.
>
> It has also been satisfying and helpful to receive from time to time from the readers of the Review suggestions with respect to authorship and subject matter. It is our hope that an increasing number of our colleagues may extend to us the assistance that comes from such suggestions in order that the quality of the Review and its usefulness may steadily be enhanced.

The scope of the reviews of progress in the special field of biochemistry is best indicated in the following list of topics and of the contributors: Biological Oxidations and Reductions, by L. Michaelis and C. V. Smythe; Chemistry of the Crystalline Enzymes, by J. H. Northrop and R. M. Herriott; The Chemistry of the Carbohydrates and the Glycosides, by E. F. Armstrong; The Chemistry of the Acyclic Constituents of Natural Fats and Oils, by G. S. Jamieson; The Chemistry of Amino Acids and Proteins, by M. Bergmann and C. Niemann; The Chemistry and Metabolism of the Compounds of Phosphorus, by K. Lohmann; Carbohydrate Metabolism, by H. E. Hinwich; Fat Metabolism, by F. Verzar; Metabolism of Amino Acids and Proteins, by H. A. Krebs; The Metabolism of Creatine and Creatinine, by K. Thomas; Acid-Base Metabolism, by J. Sendroy, Jr.; The Hormones, by O.

Wintersteiner and P. E. Smith; The Vitamin-B Group, by R. A. Peters and J. R. O'Brien; Vitamin C (Ascorbic Acid, Cevitamic Acid), R. A. Peters and H. W. Davenport; The Fat-Soluble Vitamins, by J. C. Drummond; Nutrition, by H. H. Mitchell; The Biochemistry of Muscle, by E. Lundsgaard; Liver and Bile, by A. C. Ivy and L. A. Crandall, Jr.; Animal Pigments, by R. Lemberg; The Terpenes, Saponins, and Closely Related Compounds, by W. A. Jacobs and R. C. Elderfield; Organic Insecticides, by F. B. LaForge and L. N. Markwood; The Chemistry of Bacteria, by W. H. Peterson and M. J. Johnson; Growth Regulators in the Higher Plants, by P. Boysen. There are also author and subject indexes, which, for obvious reasons, occupy considerable space.

Once again, the editors have placed under obligations to themselves a large number of students, technicians, and teachers who have come to depend on them for an important and constructive service.

*Handbook of Practical Bacteriology.* Fifth Edition. By T. J. MACKIE AND J. B. MCCARTNEY. William Wood and Company, Baltimore, 1938. Pp. xi + 586.

This is the fifth edition of a very useful work. It is not easy, even for the progressive teacher, to keep abreast of the new developments in microbiology. Aside from medicine, there are the important fields of industrial and agricultural microbiology. Much reading and study are required for even a superficial review of the more recent contributions in these fields.

It is noted by the authors that

> In preparing this edition we have taken the opportunity of revising those sections of the book in respect of which new knowledge and modifications in laboratory practice have necessitated review of the subject matter and the methods recommended in the previous edition. We have again endeavoured to keep the book within a given compass though it has been impossible to avoid expansion. As in the fourth edition, the subject-matter is divided into three parts; the first, general and introductory; the second, dealing with bacteriological and serological technique; and the third, describing the more important features of the pathogenic and commensal micro-organisms along with the methods of bacteriological diagnosis of the various infections. This subdivision is intended to assist the undergraduate reader who may use Part II only to a limited extent, e. g. for guidance in carrying out certain methods prescribed in an elementary practical course. As before, the text is arranged in large- and small-type matter. We trust the book will indicate to the junior worker the essentials of the subject and at the same time serve the more senior student or graduate to obtain some guidance in the actual practice of bacteriology. As in previous editions, illustrations have been purposely omitted, except a few diagrams introduced to assist in the explanation of apparatus, etc. In view of the continuous expansion of the text since the book was first published, the present edition is designated "Handbook of Practical Bacteriology," which seems now more appropriate than the original title.

The contents of the book are divided into three parts, two appendixes, and an index. The three parts are designated, respectively: Introductory; Bacteriological Technique; and Pathogenic Micro-organisms and Bacteriological Diagnosis. The titles of the several chapters follow: I. The General Biology of Micro-organisms; II. Immunity in Relation to Practical Bacteriology; III.

The Use of the Microscope in Bacteriology; IV. Cultivation of Micro-organisms; V. Staining Methods; VI. Animal Inoculation and Autopsy; Care of Laboratory Animals; VII. Immunological and Serological Methods as Applied to Bacteriology; VIII. Bacteriological Examination of Water and Milk; Testing of Antiseptics; Testing of Surgical Catgut for Sterility; Collection and Forwarding of Specimens for Bacteriological Examination; IX. The Pyogenic Cocci; other Pyogenic Bacteria; Pneumococcus; X. Meningococcus; Gram-Negative Cocci occurring in the Nose and Throat; Gonococcus; XI. Bacillus Diphtheriae and Biologically Allied Organisms; XII. The Tubercle Bacillus and other Acid-fast Bacilli; XIII. Bacillus Mallei; B. Anthracis and Biologically Allied Organisms; XIV. The Gram-Negative Aerobic Bacilli occurring as Commensals or Pathogens in the Intestine; Intestinal Protozoa; Aciduric Bacilli; XV. Vibrio Cholerae and Allied Organisms; Bacillus Pestis and Pasteurella Group; XVI. Bacillus Melitensis and Bacillus Abortus; Haemophilic Bacteria and Allied Organisms; XVII. Bacillus Tetani; Anaerobic Bacilli of Infected Wounds; Bacillus Botulinus; Bacillus Chauvoei; XVIII. Actinomyces; Other Streptothrices; Leptothrix: Bacillus Rhusiopathiae; Organism of Bovine Pleuropneumonia; Bacillus Fusiformis; Bacillus Necrophorus; XIX. The Pathogenic and Commensal Spirochaetes; XX. Rickettsia Group; Bartonella; XXI. The Fungi; XXII. The Malaria Plasmodia; Babesiae; Trypanosomes; Leishmaniae; XXIII. Filterable Viruses. Appendix A is called "Methods of Filtration"; and Appendix B, "Scheme of Colours for Indentifying Sugar Media."

The subject matter is arranged in convenient form and will, no doubt, be appreciated by the reader.

JACOB G. LIPMAN

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*Manuscripts* submitted for publication and communications concerning editorial matters should be sent to Dr. Jacob G. Lipman, New Jersey Agricultural Experiment Station, New Brunswick, N. J., U. S. A.

*Correspondence concerning business matters* should be addressed to The Williams & Wilkins Company, Publishers of Scientific Journals and Books, Mount Royal and Guilford Avenues, Baltimore, U. S. A.

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# REVIEW OF BIOLOGY

*Established 1926*

**Edited by RAYMOND PEARL, M.D.**
THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD.

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**The Williams & Wilkins Company, Baltimore, Md.**